Romance of Innovation

Human interest story of R&D in rural setting

Anil K Rajvanshi

About the book

This digital book presents a brief history of renewable energy work carried out since 1981 at Nimbkar Agricultural Research Institute (NARI).

Too often the record of research and development (R&D) is written up as articles in journals and books. The human interest story of the way the research was done, interactions with the stakeholders and the pushes and pulls in doing it are left out of the record.

This book is an attempt to record these details. It also shows how R&D can be done in a small rural institute and should provide inspiration to other NGOs who want to do a similar type of work.

The aim of the book is to inspire youngsters to enter the field of rural innovations and to provide challenging ideas for research and development to those who already are converts.

Dr. Rajvanshi has written in an engaging style about the romance of doing research in rural setting and has shown that with meager resources and few members of staff, very meaningful and satisfying R&D work can be done.

It is often said that good R&D requires lot of equipment, money and manpower. Work on renewable energy at NARI has shown that it is possible to do good work in little money and resources", said Dr. Rajvanshi.

There are six chapters in the book, out of which five describe the hardware development work carried out in household energy (cooking and lighting); gasification; electric cycle rickshaws and water-related problems among others. The last chapter deals with the philosophical issues and hence gives a roadmap for the future development of rural India.

The book is a very interesting read as it emphasizes the human interest aspect of problem solving for rural India. The future research areas described at the end of each chapter will certainly be very useful for persons who are planning to develop a career in research and development for rural areas.

The book is available free of cost and is available on NARI website http://www.nariphaltan.org/roi.pdf (with links to chapters) and www.nariphaltan.org/roibook.pdf (full book). This book has been written in the hope that it may inspire bright engineers to be engaged in rural R&D and thus making the book available free may help in this effort. A short video on renewable energy work is available here.

The book was released by very well-known Indian scientist Dr. R.A. Mashelkar and Dr. Rajat Moona, DG of C-DAC in Pune on 20th October.

A nice story on the book came in Daily Mail. 2 February 2015.

About the author

Dr. Anil K. Rajvanshi has more than 30 years of experience in renewable energy R&D and rural development. He did his B.Tech and M.Tech in Mechanical Engineering from Indian Institute of Technology (IIT) Kanpur in 1972 and 1974 respectively. He received his Ph.D. in Mech. Engg. from University of Florida, Gainesville, USA in 1979 under solar energy pioneer Dr. Eric Farber. He was on the faculty of University of Florida (Dept. of Mechanical Engineering) for 2 years before returning to India in 1981 to run his own rural NGO – Nimbkar Agricultural Research Institute (NARI) in Phaltan, Maharashtra.

NARI has done pioneering work in agriculture, renewable energy and sustainable development areas specially those affecting rural population. Dr. Rajvanshi has devoted the last 33 years at NARI to apply sophisticated science and technology to solve the problems faced by the rural people in the areas of energy, water, pollution and income generation, broadly based on renewable energy in environmentally sound ways.

Dr. Rajvanshi has written extensively on his work on rural self-sufficiency and has attracted the attention of the print and visual media worldwide. He has more than 160 publications; two books and chapters in various books; and 7 patents to his credit. He has been inducted into several prominent committees of the government of India at the national and state level. He is the principal author of the Govt. of India national policy on Energy Self Sufficient Talukas.

For his work, Dr. Rajvanshi has received a number of prestigious national and international awards, such as Jamnalal Bajaj Award, induction to the U.S. based Solar Hall of Fame, Austria based **Energy Globe Award**, Federation of Indian Chambers of Commerce and Industries (FICCI) Annual Award, Sweden based Globe Award, Distinguished Alumnus Award from University of Florida (he is the first Indian to receive this award), among others. He has been a featured speaker at many prominent institutes, conferences and forums, both in India and U.S. and lectures regularly on the issues of sustainability and rural development.

Besides his engineering work he is also involved in studies of human consciousness and the interaction of spirituality and technology. His **writings** on these issues have appeared regularly in Times of India in Speaking Tree column. He also writes a blog in Times of India and Huffington Post.

He is an author of a book entitled, **"Nature of Human Thought"**, which tries to bring about a synthesis of ancient Indian Yogic thought and modern cosmology and brain research. The book contains many essays on spirituality and technology and reflects his belief that sustainability and spirituality go hand in hand. He has also penned his memoirs of his US student days in a book entitled **"1970s America – An Indian Student's Journey"**.

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(A human interest story of R&D in a rural setting)

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Preface

I present in this book the romance of innovation in a rural setting. It is basically a short history of the renewable energy work at Nimbkar Agricultural Research Institute (NARI), Phaltan. This is also a human interest story of doing research and some meaningful work in the area of rural development.

I have written an account of what we were able to accomplish at NARI in renewable energy research and to show how much more needs to be done in the area of providing basic amenities to the rural population. I hope it inspires and helps others who are so inclined and it is my fervent hope that some bright research-minded reader will take up this challenge.

I came back to Phaltan from U.S.A. in 1981 after getting a Ph.D. and spending a few years teaching renewable energy at University of Florida. In late 1981 when I returned, very few Indians with an IIT degree came back. Even the ones who did come back went to big cities like Bombay, Delhi, Bangalore, etc. I went straight to rural Maharashtra which was as alien to me as any foreign country since I hardly knew the local language or the milieu.

Why I came back to rural Maharashtra is a long story and I have written about it in another book.[1] This book is essentially a sequel to that. Nevertheless it would suffice to say that I came back because of my arrogance and the naive belief that I would help change India. India did not change but it changed me since staying in rural India made me aware of the problems and challenges of the rural population, and which technologies and strategies to develop to help them. This book is an account of that experiment.

I was always inspired by Mahatma Gandhi's rural development work. Though I had read quite a number of books on him doing my IIT Kanpur days but it was in University of Florida (UF) that I read extensively on him. UF library had excellent material on Gandhi including D.G. Tendulkar's 8 volume biography.

Gandhi’s work on rural development made a tremendous impact on me and inspired me to do something for rural areas but through technology. I was also quite sure that the poverty and the primitive conditions in rural areas deeply influences a sensitive mind and too often well meaning people, even with technology background, who want to work for rural upliftment have been sucked in by the misery they see and end up doing social work only.

I was also inspired by Gandhi ji’s experiments in living simply and sustainably and have tried to follow his example though not to the extent he did. My small experiments in that direction are given in Chapter 6.

I was therefore very clear that the greatest social worker Mahatma Gandhi could not make much dent in improving the life of rural people through his social experiments so who was I to think that I will make a difference. Thus I felt that with my training as an engineer I should try to utilize my knowledge for developing technologies for rural areas and hence my effort in that direction.

However, coming to and working in the small rural town of Phaltan in 1981 was not easy. There were lots of struggles initially and very soon after my return the ground realities hit me and all my romantic notions and arrogance vanished. If I had an iota of intelligence I might not have taken this step of coming to rural India.

Yet, once I took it there was no looking back. I would like to share how one can do meaningful and satisfying R&D work even in a small rural town with hardly any facilities. This is what I call the ‘romance of innovation’ since the work was done for the very selfish reason of doing something meaningful with my life. And it is my hope that the book will inspire some youngsters to follow this dying vocation of doing R&D in engineering for rural areas.

Doing R&D in any setting is a challenging task but more so in rural setting and especially when there was no model to emulate since NARI was the first rural NGO in India in early 1980s to initiate work in renewable energy R&D. This book is therefore an account of that unique experiment.

For the first two years after we returned from the U.S. my wife Nandini and I lived in a small rented house in the slums of Phaltan. We moved into our present house, designed by me, in early 1984. Both of us used to cycle to the Institute every day – a distance of about 3 km one way. In 1984 my brother, an orthopedic surgeon who was moving to Saudi Arabia, took pity on me and gave me his old scooter which he had purchased in 1975. That was our first motorized vehicle.

In those days one had to go to Pune – a town 100 km away – to buy even small things. Now with its milk, sugarcane and horticulture economy, Phaltan has grown to be a mid-size town with supermarkets and easy availability of other services.

Telecommunication facilities were almost non-existent in those times and it was a nightmare to make a long-distance phone call to any place. One had to book a call in the early morning and if one was lucky the call would materialize by the evening. So quite a few times I would hop on the bus and go to my friend's office in Pune to make phone calls. The bus journey in those times took about four hours one way. Today the situation is better with the availability of broadband internet connections and telephone facilities to call anywhere in the world. The roads are much improved, which has almost halved the travel time from Phaltan to Pune.

When I came to Phaltan there was a flat piece of land where I was supposed to start building my energy lab. The Institute at that time had a small building and farm land with almost no other infrastructure. I got an old fan fitted in my office, and that was the only fan in the whole Institute. Besides one rarely had electricity so the fan was mostly non-functional!

In the early days of setting up my lab, it was very difficult to get engineers and scientists. It took me nearly four years to get the lab to become functional and hire decent staff. Even now there is a tremendous problem in getting good staff. The situation has become worse because we cannot compete with the very high pay packets being offered by the industry and the government.

I now realize that one of the biggest drawbacks in setting up a research Institute in a rural area is getting good people to come and work in it. The rural infrastructure

precludes any long-term commitment by people to work in such institutes. This has been the main reason why NARI has remained small. Still, even with the small staff, meager budget and limited infrastructure we have been able to do reasonably good work with lots of firsts to our name.

I have always believed that good research can be done by thinking deeply about the problems and one can extract a huge amount of information from simple and clever experiments. In fact sometimes too much money and equipment are a hindrance to good research. We have shown this in our lab where we have been able to accomplish the entire R&D work in renewable energy **from 1981 till the present in a total budget of Rs. 2 crores (Rs. 20 million) only!**

Our work at NARI has mostly focused on **developing devices, hardware and policies for rural development with special emphasis on the use of high technology for a holistic and sustainable India.**[2] Some of these technologies and ideas have been picked up nationally and internationally, and that has been an exhilarating experience.

For example, our work on Taluka Energy self-sufficiency became a national policy (Chapter 3). Similarly our pioneering work on ethanol from sweet sorghum[3] is now established nationally and internationally. So is our work on biomass gasifiers, safflower, multifuel lanterns, ethanol stoves, electric cycle rickshaws and vehicles for the handicapped, etc. All these pioneering efforts have inspired people all over the world. For our efforts in rural development we have also received quite a number of prestigious national and international awards.[4]

India is a young society with 54% of its population below 25 years of age. The aspirations of this young generation, majority of whose members live in rural India, are not being fulfilled. With increasing exposure to mass media they aspire to a better quality of life, which I think can be made possible with development and application of technology especially for them.

It is also a matter of shame that 67 years after independence we have 60% of our rural population living in primitive conditions. They lack electricity, clean cooking fuel, potable water and toilets in their homes. Somehow modern technology has not touched their lives.

To find solutions to these problems offers the greatest challenge for any engineer or technologist and I feel that most of the Indians, wherever they are in the world, should help in trying to solve these problems with the help of advanced tools of science and technology. After all what we are and wherever we may be is because of the early life that we spent in this country of our birth and we should give back something to it. The real challenges are in India and if we can improve the lives of our rural population then we would have solved the problems of $1/5^{th}$ of mankind!

Presently our greatest problem is that most of the engineers and technologists from our best schools opt for non-engineering careers where the pay packets are higher. India spends a huge amount of money on their education and yet they do not use their technical education for India's benefit. Unless and until this problem is rectified India will always remain backward in technology and hardware.

The reasons for this state of affairs could be many - one of which could be our faulty schooling system [5] which somehow neither encourages young students to tinker nor inspires them about the romance of science. Another reason could be that our top engineering schools do not challenge our bright students [6] in technology areas. I hope the work described in this book will challenge some of these bright students to take up technology related work for rural development.

In my innumerable interactions with young students all over the country I have always got the impression that they want to do something meaningful in their lives. Yet, they are neither shown the opportunity nor the path because of the paucity of good and motivated teachers. I am sure if given a chance and provided motivation our engineering students can do wonderful work to help the country.

During my interaction with these young students I have often been asked how I have continued doing this type of work despite all odds. I think the answer is '*junoon*' or passion.[7] Without a single-point focus and passion for doing something meaningful one cannot continue on this path. That is the romance of innovation. Also if the focus is only on money then it is not the path to be taken.

Junoon not only provides the energy to do something but also takes the mind away from external pressures. One can then do things one likes and not what others want you to. I have never been afraid to tackle any problem and challenge. This is what my Ph.D. has taught me. It is a training of the mind and given enough time and patience one should be able to attack any problem. Readers will see how we have managed to work on myriad problems facing rural India.

Another way in which *junoon* is sustained is by developing hardware. **The motto in our lab has been 'just do it'!** Even when the theoretical challenges have been daunting we have solved them by developing devices first, experimenting upon them, and then developing appropriate theories. In this we have followed the old school of thought where experiments often showed us the theoretical underpinnings of the design.

Most of the problems we have worked on have come from our area. I feel that all the problems exist right in front of us. If each one of us can provide solutions to them then we could rapidly develop India. There should therefore be a concentrated effort to expose students in our schools and colleges to the local problems and their possible solutions rather than giving them esoteric problems which unfortunately have no connection to the local conditions.

Besides the technological problems we also faced social ones. For example in the earlier years the bathrooms in our Institute were filthy and since we were quite far from town nobody came to clean them. So when I proposed that all of us will clean them there was a revolt by the staff. Even when I took the lead in cleaning them [8] they did not budge. Thus not only do we need to train the scientists and engineers in R&D but also in the ethics of work. This training nevertheless needs to be imparted during school and college days.

The romance of innovation is like *Yoga*. The goal is clear and attainable and by pursuing it one forgets about all other problems, odds and obstacles. For rural development it is essential that single-minded focus on doing meaningful work becomes the paramount purpose in life. How we can teach this to young students is the biggest challenge and I try to engage the students on this subject[9] at any opportunity I get.

There have been many times when our research has not progressed as planned because of so many uncertainties in the rural set up. I have utilized that time to think deeply about spirituality and the problems of rural India and have written about these issues.[10] I have also tried to utilize the knowledge of science and technology in the realm of spirituality and hence have tried to blend spirituality with technology.[11] I think this is a novel and innovative theme. Writing on these issues has been very enjoyable and therapeutic, giving me new vigor and motivation to overcome challenges and hardships. It has also made us well known world over, and one of the tangible benefits has been a good number of interns[12] who have come to help us from across the globe.

I believe that thinking deeply and writing about higher issues is also a part of the romance of innovation since it could be in any field, whether technology or spirituality. However the ability to think and work on these higher objectives is achieved only when one simplifies one's life. Once the basic needs are met most of the energy can be focused on doing something that is enjoyable. Living in rural areas helps in simplifying one's life and becoming spiritual.

With hardly any avenues to spend money and availability of very few amenities, one starts living a simple life, which is the first step towards spirituality. Initially one may not like it but with time one starts to enjoy the benefits of a simplified life. I recommend such a life for anybody who believes in sustainability because when everyone becomes sustainable in their personal life, the world will automatically become sustainable. I feel one can live a simple, high thinking and emotionally satisfying life with much less energy, and in our small way we have shown that it is possible (Chapter 6).

This does not mean that we should live a primitive life. In fact the extremely sophisticated technologies that provide modern tools of communication and power are an important part of reducing energy consumption, thereby promoting sustainable living. What is needed is to curb our consumptive lifestyle, which promotes greed for resources, and spirituality helps in doing that. I believe the mantra of India's development should be **'Spirituality with High Technology'.** [14]

I feel very lucky to have come to rural India so that I could develop simplicity in my daily life and now I feel that it is my duty and responsibility to spread the message. This I have been doing through my work, speeches and writings, and this book is another small step in that direction.

I have always believed that the purpose of human beings is to first become happy and self contented and then give something back to the society. Giving back to society gives a purpose in life and brings joy and happiness.[15] I feel our work in rural development is a small contribution to society. Towards that goal we have made available most of our publications and work on the net. [16]

Organization of the Book

I have decided to publish this as an e-book and make it freely available. These are e-book times with a proliferation of book readers like Kindles, iPads, etc. Young people, at whom this book is primarily directed, are computer savvy and more comfortable reading e-books than physical ones. Also, e-books lend themselves to the use of links as reference material and have been extensively used in this book. I am sure some of the research minded readers will find them useful.

I have also appended at the end of the book link notes so that the readers are not distracted by the links while reading the book. The link notes contain a brief description of different links and can be read leisurely by research minded readers.

All the chapters in the book are standalone and can be read in any order. Since there was quite an overlap in the technology development at NARI, rather than arrange the

chapters chronologically, I have decided to place them according to areas of development.

Since this book is primarily meant for younger readers, I have included at the end of each chapter unsolved problems and future research areas on renewable energy for rural applications; these are in addition to those appearing at appropriate places in the chapters. I hope these will provide a challenge to idealistic young engineers and technologists.

Besides the hardware oriented work that we have done at NARI, I have also thought deeply about the problems and possible solutions of rural India. I have written about them and published them in various newspapers and magazines. I feel they may provide readers food for thought and have thus included their genesis and rationale in chapter 7, titled 'Roadmap for Rural India'.

Finally, it is my fervent hope that this book conveys the romance of innovation, and if somebody is inspired by our work it will give us great joy and satisfaction.

Anil K Rajvanshi
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I must thank Ashvina Vakil for doing a commendable job in editing it – she did it as a labor of love; and to my daughter Madhura Rajvanshi for suggestions on cover design.

Finally I would like to thank my wife Nandini Nimbkar who read umpteen drafts and gave valuable suggestions; to S. S. Aherrao for typing it and to all my staff members past and present who contributed in the projects described in the book.

Household Energy

Almost one third of the renewable energy projects undertaken at NARI have focused on household energy. This is based on our belief that rural poor have the same aspirations as all of us and their quality of life can be improved by developing easy to use and environment friendly devices for cooking and lighting from locally available resources. This short history of R&D efforts at NARI in these areas is divided into two parts: production of renewable fuel for rural households; and development of devices for cooking, lighting and production of clean water. All the projects undertaken at NARI are hardware-oriented.

Production of Renewable Fuels

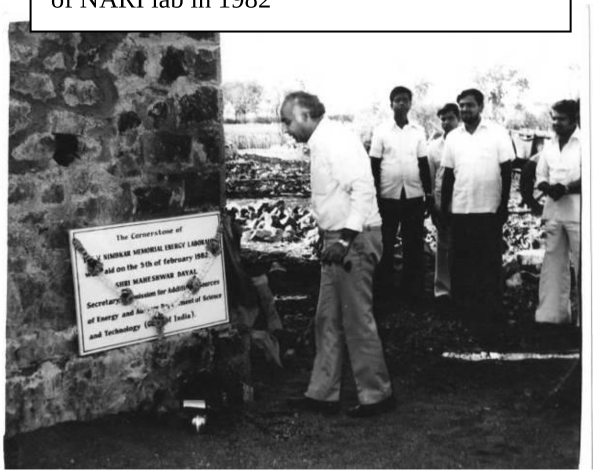
In late 1970s I taught for two and half years in Training in Alternative Energy Technologies (TAET) program at the University of Florida (UF). TAET was set up at UF by a huge grant from USAID to train scientists and energy planners from developing countries in the areas of renewable energy. One of the topics that constantly came up was the development of renewable fuel for cooking and lighting in rural areas. I therefore thought that ethanol would be an excellent renewable and non-polluting fuel for such purposes. The idea was to replace fossil fuel like kerosene and liquid petroleum gas (LPG) with renewable fuel, and ethanol seemed to fit the bill.

Studies on ethanol production had shown that the maximum energy is used in its distillation from the fermented mash; I thought it would be useful to use renewable solar energy to distill it.

When I came back to India and started working at NARI in 1981, the first project I did involve solar distillation of ethanol using a simple solar still. Since my Ph.D. work in U.S. was on solar distillation of water ,[17] I thought of using a similar technology for ethanol distillation.

So I wrote a small proposal (Rs. 1.2 lakh for 2 years project) on solar distillation of ethanol to the Commission of Additional Sources of Energy (CASE) - a predecessor of

Department of Non-Conventional Energy Sources (DNES), both Government of India (GOI) entities. CASE was run in those days by Maheshwar Dayal a dynamic engineer from Indian Atomic Energy establishment and who later on became the Secretary of DNES. I went to see him in Delhi and he immediately sanctioned the project though fully knowing that I did not have a lab or the manpower. That was our first project. I have always remained grateful to him for reposing faith in me and our work.



Maheshwar Dayal laying the foundation stone of NARI lab in 1982

I think he was quite impressed by the fact that though I had worked under the solar pioneer Dr. Farber in US, I decided to come back and work in rural India. Mahesh was a really helpful person – he also laid the foundation stone of our lab at NARI in 1982. His bright career was unfortunately cut short by his untimely and tragic death in early 1990s.

Phaltan in 1981 was really a very small town, almost like a big village with hardly any facilities. Our Institute was situated about 4-5 km from the town and we had neither fabrication facilities nor staff! I designed the still and got it fabricated by a local welder. I had to sit with him and get it fabricated as per my specifications, though the quality of work left much to be desired.

I had brought back a good amount of lab equipment from the U.S. including strip chart recorder, thermocouples, constant temperature baths, even silicone glue, and all these helped me to assemble and experiment on the simple solar still. The Indian participants in the TAET program at UF had told me what research equipment is available in India and so I thought in a remote rural area of Phaltan some basic equipment will be needed to immediately start work and this helped me to decide on what to buy. After I came back I realized that to get even simple things like thermocouples from Mumbai was quite a chore since it took almost a month or two to get them. In those days with lack of phone connection from Phaltan the only means of communication were letters by post and this delayed the purchase quite a

lot. The equipment from US therefore helped us do our work for 4-5 years before we established good contacts with lab equipment vendors.

When I tested the still, I found that it only produced ethanol of 20-25% (v/v) concentration, which was not enough to be used as cooking fuel. The next step was to increase its concentration and that could be done by using a small vacuum. Since we did not have the facility to fabricate such a still, I designed it and a friend of mine, Mr. M. G. Pawar, got it fabricated at his workshop in Pune. The still (pictured) worked in batch mode with vacuum being pulled in the morning and ethanol collected in a condenser in the evening.

This single-effect simple vacuum solar distillation unit showed that one could produce a 40-60% (v/v) ethanol water mixture [18] from fermented mash (7% (v/v) ethanol). In 1983-84, we developed a 1 kW (thermal) stove to utilize this mixture for cooking purposes. This stove (shown) worked on the principle of surface evaporation of ethanol from the mixture; once lit, the stove kept on burning till either the air supply was stopped (by covering the stove with a lid) or the ethanol evaporated out of the mixture. This, to our knowledge, was a unique stove running on low concentration, i.e., 40-60% (v/v) ethanol.

While we were working on the solar distillation unit, we also started a program on the use of sweet sorghum as an alternative crop for ethanol production.[3] The main crop for ethanol production in India is sugarcane. It is an 18-month crop and consumes a huge amount of water. The idea was to use an alternative crop which would be of short duration and use less water. Sweet sorghum, which is a 4-month crop and consumes around 40% less water than sugarcane, is one such crop. It is a multipurpose crop, providing grain from its ear head, and sugary juice, which can be fermented to produce ethanol, from its stalks; the bagasse is excellent fodder for

animals. Hence, sweet sorghum provides food, fuel and feed from the same piece of land. Besides the output/input energy ratio for this crop [18] was quite high making it very attractive to grow for fuel production.

Sweet sorghum was introduced in India by our Institute, NARI, in the early 1970s. Our program included breeding better varieties of sweet sorghum, improving fermentation efficiency of its juice, and finally solar distillation of ethanol. In the early 1980s we set in motion **the world's largest program on the use of sweet sorghum for ethanol production.**[3] We were almost 30 years ahead of time because in late 2000 there was a great surge worldwide in programs to promote usage of sweet sorghum for ethanol production. We are proud to state that largely because of our efforts in the 1980s and '90s, the Government of India (GOI) launched a national program on sweet sorghum for ethanol production around 2005. Also our Madhura sweet sorghum variety has been tested and sown in more than 15 countries.

Our simple solar still gave us good publicity and was written up in local newspapers. One day a smartly dressed village woman showed up at our lab and told us that she wanted to buy this unit and would pay for it immediately in cash. I told her that this was just an experimental still and not for sale, but she insisted on buying it. When I enquired why she was in such a hurry, she replied that her business was distilling illicit ethanol using a wood-fired boiler and she and her gang were always getting caught by the police because they could detect the smoke coming out of the distillation unit! She thought our solar still, which worked silently and without smoke, could easily solve this problem.

Distilling and use of ethanol in India is controlled by stringent excise laws and one needs a special license. Getting an alcohol license is very difficult since there is a lot of corruption in the excise department. Consequently, illicit distilling activities thrive in the rural areas. There are rough estimates that illicit ethanol production industry is nearly 5 times bigger than the regular one.

Our work on this simple distillation unit also pointed to the fact that with better vacuum and a specially designed distillation column, solar energy could be used to

distill high purity ethanol. I then wrote a proposal to Department of Non-conventional Energy Sources (DNES), GOI, for setting up probably the world's first pilot plant of solar-powered ethanol distillation.[19] It was designed to distill 50 liters of 95% (v/v) ethanol per day.

In 1985 we started work on this plant and finished the testing and analysis by 1989. In 1985 I hired Rajeev Jorapur, an engineer who had just finished his B.Tech in Chemical Engineering from IIT Bombay and together with a four-member team of technicians we set up the plant. We hired a distillery consultant to design the distillation column. All his experience centered around designing 30,000 liters per day (lpd) plants running on steam, and he found it a challenge to design a low temperature (60-70°C) plant of 50 lpd.

Solar powered ethanol distillation plant (1988)

We went through a lot of trials and errors, but were able to set up the plant in 9-10 months. Except for simple welding, drilling and grinding machines we had no equipment for making flanges or for machining parts. Our resourceful technicians got them fabricated in Phaltan and we had the stainless steel parts fabricated in Pune.

In those days Dr. A.P.B. Sinha a deputy director of National Chemical Laboratory (NCL), Pune was a member of our advisory board. He used to come to Phaltan to advise us and review our work. Apparently he told some of his colleagues that what

he could not build in 10 years in NCL, Rajvanshi and his group has done in 10 months!

This scorching pace was achieved by running the lab in an industrial mode. I would have weekly meetings with all my staff and very detailed time table was made and followed through. Though we hardly had any facilities or equipment but the pace of work created a momentum and we improvised as we went along. We would do the design and get it fabricated and then experimented on it. If the design did not work then immediately we modified it. This has been the motto in our lab of constant discussion and improvisation and we have used it in all our projects. I believe in a rural setup this is a good model to follow and feel that with high expectations from the staff good results do take place.

We ran the plant continuously for about two years and found that for 70% of the year it could run on solar energy; for the remaining 30% (during the rainy season) it needed auxiliary heating from a wood-fired boiler.

In 1987 I presented the work on our solar distillation plant[19] at the International Solar Energy Conference in Hamburg, Germany. The European scientists could not believe that a small NGO in rural India could set up such a pilot plant. I was interviewed on a German radio show, and the Chairman of European Economic Commission (EEC) on Bioenergy, Dr. David Hall[20], invited NARI to join the sweet sorghum mission of EEC. David visited NARI in 1994 and because of him NARI became the first Indian organization in the early 1990s to become a member of EEC sweet sorghum consortium.

This distillation plant gave us a lot of publicity but an unintended outcome of the publicity was the visit of excise officials to my residence. One Sunday afternoon a jeep full of excise officials from Satara arrived at my residence and demanded to know who had given me permission to distill ethanol and threatened to put me in jail. They had read about our distillation plant in the newspapers. I informed them that this was an experimental pilot project funded by the Government of India, so we should be exempt from taking such permission; however, they insisted we had to get a state license to distill ethanol.

We asked them to give us an appropriate license, but they said that there was no provision to give a distillery license to such small experimental units, especially one running on solar energy and using sweet sorghum fermented juice as raw material. Their rule books said that the plant should run on steam and should use only molasses as a raw material. Such are our archaic laws which have not changed since they were formulated by the British in the early 1940s!

We approached Mr. Sharad Pawar who was the Chief Minister of Maharashtra at that time. He quickly understood the importance of using alternative crops for ethanol production and sanctioned a special license for our Institute. The license was issued in 1988 and we had to renew it every year. This proved to be quite a headache - three sets of the application with detailed attachments had to be provided every time. In 1998 the excise department took away the license, stating that since we were not running the plant, we did not need it! This was despite the fact that we were paying the license fees regularly. I guess they wanted money under the table, which we refused to give.

Because of the publicity given to this plant we had a continuous stream of visitors coming to see it from all over the country. However, when we tried to sell our technology to industries we were not very successful; my guess is we were way ahead of time. In 1992 we almost set up India's first distillery running on sweet sorghum near Mysore. A detailed project, based on our technology, was developed by one party to distill 10,000 lpd ethanol from sweet sorghum. However the markets were not favorable and the GOI did not have any policy regarding the use of ethanol for energy purposes. This was the disadvantage of being ahead of our time!

We stopped producing ethanol in our plant in the mid-1990s and dismantled it in 2000.

Now, almost 20-25 years later, there is a tremendous interest in India and worldwide in using sweet sorghum as an alternative crop for ethanol production and the use of renewable energy like solar energy for its distillation. We get a large number of inquiries about our solar plant and sweet sorghum seed. We have supplied large quantities of our 'Madhura' sweet sorghum seed in India and all over the world.

Energy security for India is a major cause of concern. We import 80% of our oil requirements and have become the 3rd largest oil importing country in the world after China and US. In the absence of local oil reserves there is a need to use suitable sugar crops and agricultural residues (India produces 600-800 million tons/year) and convert them into crude for producing chemicals and fuel. This is a challenge to all engineers and scientists.

Development of Lighting and Cooking Devices

Lanterns

In 1981 Phaltan had a tremendous shortage of electricity, and we often had to light hurricane lanterns at night. Coming from Lucknow and having been educated at IIT Kanpur and in the U.S., I rarely had the occasion to use hurricane lanterns. So when I used them I discovered that their design had not changed since the early 1900s when they were introduced in India. I started thinking of how to improve their lighting efficiency and did some preliminary experiments on the lantern. A small note on how to improve them was written and sent to Mr. K. C. Pant,[21] Chairman of the Advisory Board on Energy (ABE), GOI. He had put me as an advisor on a couple of committees in ABE. He liked the note on lantern improvement very much since we were probably the first to suggest the use of tools of modern science and technology to improve a humble lantern.

In those days Mr. Jairam Ramesh (who later became GOI Minister for Rural Development) used to be an officer on Special Duty (OSD) in the ABE. Mr. Pant entrusted him with the task of taking forward my ideas on the improvement of lanterns. Jairam moved really fast and got me a project on improvement of lanterns for rural areas, and in 1984 we received a substantial grant for the same.

Noorie lanterns, 1988

I hired Sudhir Kumar, a fresh Ph.D. in Chemistry from IIT Bombay, to work on the project. He was a quick study and though a chemistry person, learnt the basics of engineering and fabrication and did good work. Our first task was to

measure the lighting and fuel efficiency of all the existing lanterns used in rural huts. This measurement and comparison data in 1984[22] was probably the first such data reported anywhere and became a benchmark study on kerosene lighting, which was used and quoted by the World Bank and other agencies.

We developed quite a number of designs for improved lanterns and ultimately produced a pressurized mantle lantern called 'Noorie'[23] (pictured above) which to my knowledge was the first real improvement in kerosene lanterns since Petromax lanterns were developed and introduced in the U.S. and Europe in 1920s.

These pressurized mantle lamps work on the principle of evaporating kerosene fuel to vapor; this kerogas is combusted to light a silk cloth mantle coated with a Thorium/Cerium (Thoria) mixture. The improvement in the Noorie lantern[23] included ease of lighting by using kerosene as lighting fuel instead of ethanol as used in Petromax lamps; better combustion of the air-fuel mixture by designing an efficient venturi, which also resulted in lowering the pressure of the kerosene container; improving lighting efficiency by designing a better fuel combustor; and using the heat of flue gases to cook small amounts of food.

The most important improvement was to increase the combustion efficiency of Noorie lamp and one of the ways to do so was to measure the signature of flue gases which would tell us whether the combustion was complete or not. For this we decided to purchase a Gas Chromatograph (GC).

In late 1980s, GC was a costly piece of equipment. With a grant from ABE we ordered one from Toshniwal Instruments (TI). In those days TI in Mumbai was the only Indian company manufacturing them. We asked for the quotation and then wrote to them to reduce the price by 30% ! TI people were quite intrigued to get an order of GC from a small rural Institute and so a very senior manager came from Mumbai to Phaltan to discuss the purchase.

He asked me who is paying for the GC. When I told him it will come from the grant from ABE he asked me why I was keen on reducing its price. I explained to him that

if I reduce the price of GC we can request ABE to allow us to use the saved funds under different heads of the project like fabricating more lanterns of different designs, etc.

He started laughing and told me that he sells GCs to major GOI institutes and IITs and most of the time the concerned scientists instead of reducing the price ask him to mark it up by 20% or more! That is how the corruption took place in these labs.

I was shocked and pained to hear this and wondered what type of role model these teachers will provide and what examples they will set for the students! This was in late 1980s and I am told that such instances of corruption in these premier institutes and labs have increased manifold.

Besides the improvement in combustion and ease of use, one of the things we tried in 1986 was to improve the thermoluminescent mantle itself so as to make it strong and more efficient. I thought of using high temperature lightweight material for the mantles and new salts for thermoluminescence. We thought that the high temperature, lightweight tile materials used in the reentry space shuttle might be very useful for this purpose. I wrote to the Space Department in Bangalore and they were thrilled that ablative material from reentry rockets would be used to improve the humble lantern. The Space Department went on to advertise the fact that space materials were being used for rural areas!

They sent us high temperature glass cloth and ceramic wool, which we tried as mantle materials. However they failed to glow when coated with thermoluminescent Thoria salts; since their thermal mass was high and hence could not attain the high temperatures necessary to produce light. We solved the problem of mantle stability by redesigning the lantern so that the impact on the fragile mantle could be minimized. This was achieved by improving the heat transfer characteristics of the fuel evaporating tube so that the extra loop of this tube, as in old Petromax lanterns, was not needed. This extra loop used to be the main culprit in mantle breakage. All these design features were incorporated in our 'Noorie' lantern.

We revisited the mantle development work in 1994 with the help of GOI Department of Science and Technology (DST) funding. The idea was to do a detailed theoretical study on how the present rare-earth coated thermoluminescent mantles produce bright light, and then to find new and better materials to replace them so as to improve their lighting efficiency. Since I did not have the requisite knowledge of solid state physics needed for the study, we hired a senior and reputed scientist from Bhabha Atomic Research Center (BARC) as a Principal Investigator. He was a physicist and hence we thought he will be competent to help us out in this study. However he was not able to deliver the goods and we lost a tremendous opportunity to make a contribution to the improvement of mantles.

Since we were distilling ethanol at that time from our solar distillation plant, we thought of developing an ethanol version of the 'Noorie' lantern. The design of the kerosene 'Noorie' lantern was tweaked to take into account the thermophysical properties of ethanol/water mixture and we were able to run the lantern on 85% (v/v) ethanol concentration. We finished the work on lanterns in 1989 and did not take up the work on lighting for households till 2004. This was because we got involved in developing a large scale sugarcane leaves gasification system [24], a system of detoxification of distillery waste[25], and electric cycle rickshaws[26] among other projects.

Our lantern work gave us good publicity since it caught the imagination of people and the mass media by the fact that a simple lantern could be improved by the best tools of science and technology. We were therefore invited to give talks and show it at many seminars, workshops, etc.

In 1989 we were invited to show it at Teen Murti House in New Delhi in an exhibition to be inaugurated by Mr. Rajiv Gandhi, the then Prime Minister of India. I got a telegram from the concerned office just two days before the lantern was to be shown. I immediately replied with a telegram asking them to send me a helicopter! Obviously the babus in the office realized their mistake and sent me a telegraphic reply saying that I could come at my own leisure. I took the earliest available flight from Pune to Delhi, packing the lantern in a small box, which I carried as hand luggage.

In those days, Pune airport was just a tin shed and the Indian Airlines flight to Delhi was in the evening. As I was standing in line to get the boarding pass, the electricity at the airport failed. The whole airport became pitch dark and the airport staff ran helter skelter to get candles since there was no electricity generator at the airport! I went to the Manager of Indian Airlines and told him that our 'Noorie' lantern could light up the whole airport provided we got kerosene! He obviously told me that it was not possible to do so.

Another time we were approached by the local shepherds to give them a lantern to keep the wolves away from the sheep at night. We provided them with a couple of lanterns, which seemed to serve their purpose. Our lantern was 15-20 years ahead of time and came much before the Solar LED lanterns which are in vogue today.

We also shipped quite a few of these lanterns to California in 2000 since some Americans were afraid that the Y2K problem would cause all the facilities to collapse and they wanted to stock a reliable lighting device. Our 'Noorie' lantern seemed to have caught their imagination.

We tried hard to sell the technology of 'Noorie' to vendors and manufacturers in India. Most of them wanted to take a sample and see what they could do and were not interested in technology transfer. In the early 1990s Union Carbide (India) became interested in taking up our technology but I guess they got burdened by the problems of the Bhopal Gas Tragedy and so dropped the project.

Even today there is a tremendous shortage of electricity in rural areas and hence we feel that for quite a number of years from now on an efficient liquid fuel lantern can play an important role in providing adequate light to rural huts.

Cooking devices

Alcohol stove

In 1983 my good friend and fellow IITian Mr. Anil Agarwal, a well-known environmentalist who started the Delhi based NGO called Center for Science and Environment (CSE), invited me to Delhi for a conference/workshop on cooking

energy needs. This workshop gave me good ideas on the needs and problems of rural cooking energy and on what could be done in this field.

After my return from the conference I thought that a modified Janata cooker would make a good rural cooking device. These slow steam cookers which were in vogue in north India in the 1950s and '60s used to run on charcoal. We experimented in our lab on these cookers (they worked on the heat pipe principle) in the early 1980s and tried to run them on wood and kerosene. One of these cookers (pictured), manufactured in large numbers in the early 1950s in Delhi and sold all over the country, was used extensively by my mother in the 1960s.

In 1984 I got an old cooker from our Lucknow house and tested it to see its efficiency and how it worked. We developed complete performance parameters of these cookers running on kerosene and wood. This preliminary work on Janata cookers helped us to later develop them for the ethanol Lanstove™[27].

Our work on Janata cookers, published in NARI's first energy booklet [28] in 1986, was the first attempt anywhere to characterize their performance. We feel that this work helped the development of Sarai and Bachat Cookers in the late 1990s.

In 1994 we hired a fresh Ph.D. in materials science from Uttarakhand for our mantle work. Anytime we hired scientists I used to ask them about the problems faced by rural folk in their area. He said that the biggest problem was distillation of illicit alcohol in the hilly regions of Uttarakhand. The men brewed it, drank it, and then beat up their wives. The women had to walk quite a distance in the hilly regions to collect wood for cooking. I thought if we could create a stove which would use this low concentration ethanol (almost like vodka!) for cooking then the men may not drink it and the women would not have to walk 5-10 km to collect wood. This might kill two birds with one stone!

Besides taking care of the drinking problem, another reason we worked on low concentration ethanol was its safety as household fuel. Pure ethanol is a very inflammable and extremely hazardous fuel. By diluting it to 60% ethanol/water mixture it becomes safe fuel for cooking and lighting.

Since we had already worked on a low concentration ethanol stove in the early 1980s we revived that surface evaporation design, but found that even after complete burning of ethanol there was still 15-20% ethanol left in the mixture as it could not be evaporated. This was quite a waste of precious ethanol. We realized that somehow the whole mixture had to be evaporated and the ethanol combusted. For a couple of years we worked on the design of the system to evaporate the mixture and burn the ethanol. In 2003, after we were convinced of the efficacy of our design, we wrote a proposal to the Ministry of Non-conventional Energy Sources (MNES).

For most of our projects we have first done the preliminary work in our lab, and only after we believed that the design would work, did we write a proposal for funding agencies. This strategy has always borne fruit. The project money then allows us to tweak and optimize the design.

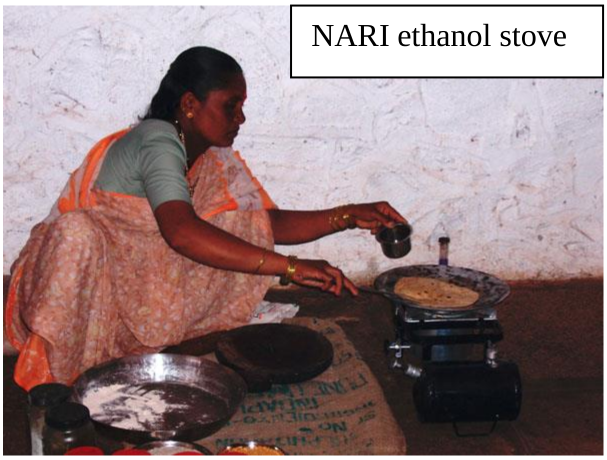
In 2004 we started work on developing a low-concentration ethanol stove for rural areas[29] and finished it in 2006. To our knowledge this was the first serious effort anywhere in the world to develop a stove which could run on the illicit liquor (~60% ethanol/water mixture) that is produced in rural areas.

In 2003 I had published a paper on the strategy of cooking and lighting for rural areas.[30] This paper, based on our work and experiences in cooking and lighting, elicited tremendous response worldwide[31] and helped start international efforts on a fan powered woodstove (Philips and Oorja stoves) and the use of ethanol for cooking and lighting (in Africa and Latin America). One of the key recommendations in this paper was to set up a national mission on cooking and lighting.

Early in 2004 I went to New Delhi to meet Mr. K. C. Pant[32], who was at that time vice chairman of the Planning Commission, GOI, and apprised him of our work. He liked

the idea of a cooking and lighting mission and I was invited to address the rural energy group in the Planning Commission. The outcome of this meeting was a policy document to take this idea forward. [33] Unfortunately by May 2004 the BJP Government fell and the new Planning Commission under the UPA had other ideas! The national mission on cooking and lighting is still in limbo; it needs to be revived so as to provide the basic necessities of life to 60% of our rural population.

In any case we developed our low-concentration ethanol stove in 2005. [29] We tested it for a year by asking all the farm laborer women in our Institute to use it to cook.



NARI ethanol stove

All the women used it by turn to cook a complete meal for a family of four or five. We collected the necessary data and discovered that almost all the women liked it. However, the use and storage of low concentration-ethanol required an excise license, and this proved to be a problem. In 2012 we sold the technology of this stove to a company in Indonesia, where the laws on use of ethanol in the household sector are much less stringent than in India.

This unique low-concentration ethanol stove[29] helped spawn a number of international efforts in developing alcohol stoves for cooking. An alcohol stove program in Africa called GAIA, funded by the World Bank, probably came about as a result of our work.

As we were testing our alcohol stove, a couple of women suggested that this ethanol should also be used for lighting purposes. We had already done some preliminary work on an ethanol lantern running on 85% (v/v) ethanol-water concentration in 1989, and thought of extending that work to make a lantern run on 50-60% (v/v) concentration. We wrote a proposal for the Department of Science and Technology (DST), GOI in 2007 and developed the necessary lantern by 2009.

We tested this lantern in many huts without electricity near Phaltan and it was appreciated by the users. They suggested that instead of filling ethanol in a small tank and continuously pumping it, as was done in the existing Petromax lantern design, a better design would be one with fuel storage as in LPG cylinders, where with a flick of the valve the fuel (in this case low concentration-ethanol) would flow and could be ignited to light the lantern.

Lanstove™

Alcohol lanstove with modified Janata cooker

During our kerosene and ethanol lantern work we had realized that the heat of flue gas could do a small amount of cooking like boiling eggs, making tea, etc. We thought of increasing the power of the lantern and using a modified Janata cooker to cook a complete meal for a family of four or five. This made the mantle lantern devices very efficient because heat, which was wasted before, was now used for cooking.

We used both the above suggestion and the idea and embarked on the design and development of an alcohol Lanstove™.[27] This lanstove (lantern + stove) gave excellent light and cooked a complete meal for a family of five. For this invention we were given the prestigious Energy Globe Award[34] in Stockholm in 2009.

The Energy Globe Award[34] gave us lots of publicity both in print and the mass media. A good outcome of this publicity was that the Secretary in the Ministry of New and Renewable Energy (MNRE) wrote to me asking how the GOI could help in this project! I went to New Delhi and told him that we would like to put this lanstove in about 50 huts. He immediately agreed to the suggestion and asked me to write a proposal.

From my previous experiences with the Excise Department regarding the distillation and use of ethanol for household purposes, I thought it would be better if we discussed this issue with them first before writing a proposal.

The Excise Commissioner told us that, according to the existing law, each hut where we would put our ethanol lanstove,[27] would have to have an alcohol license. Getting an alcohol license in India is a nightmare due to the large number of archaic rules, and it is probably easier to go to the moon!

He also added in a matter of fact way that if by chance any of the users drank this denatured alcohol and died, he would put us in jail for three months without any questions asked!

On the one hand we were trying to get these poor people a good lighting and cooking device and improve their quality of life, and on the other, the archaic government laws made it impossible for us to proceed. When we mentioned this to the MNRE, they said they were helpless in this matter since excise was a state subject!

Kerosene lanstove

We therefore decided to abandon our alcohol lanstove project and went back to the drawing board and designed it to run on kerosene instead. Almost everybody commented on why we were going backward from clean renewable fuel like ethanol to dirty fossil fuel like kerosene.

Kerosene lanstove

Most people do not realize that all fuels are dirty and it is only the combustion process which makes the fuel clean or dirty. Our kerosene lanstove[35] (pictured) produces only 4-5 ppm carbon monoxide (CO) levels in huts, and burns with no smoke. Its particulate emission levels are equal to those from an LPG stove[36] and hence it is as clean as an LPG cooking device. Besides Life Cycle Analysis (LCA) done on it showed that it was nearly five times more efficient than electric lighting and cooking![35]

In order to measure the particulate emissions from our lanstove we developed a very simple device to measure soot.[36] The device works on the idea of collecting soot on a metal plate and then measuring the reflection of light from this plate using a smart phone. The reflected light is correlated with the amount of soot collected. We believe that this device is simple to use and very cost effective. Presently the soot determination methods use very costly particulate counters, are tedious, and use sophisticated labs to do it. We feel that our soot measurement device can also be used to evaluate soot production from biomass and other cook stoves used in rural huts. We have not patented it and have made it available free for anybody to use it.

Since our lanstove is a mantle type lighting device it produces good amount of heat via radiation. There is a great scientific and technological challenge to produce glass for these lanterns which can block all the heat. This will produce cool light and make the cooker even more efficient since all the heat wasted in radiation will go into flue gas for cooking.

One great advantage of ethanol is that it can be produced locally whereas kerosene has to be imported and is a product of fossil fuels. However, technology development worldwide is rapidly progressing and in the near future it may be possible to produce kerosene-like fuels from agricultural residues and other biomass. Kerosene will then become a renewable and clean fuel for rural households.

With the help of DST funding in 2011 we successfully put 25 kerosene-powered lanstoves in rural huts in four villages around Phaltan[37] and tested them for one year.

One of the biggest challenges we faced in this project was the availability of kerosene. This was primarily because of two reasons: firstly, the GOI has limited the quota for poor people to just 5 liters of kerosene per family per month. This is a ridiculously low amount and cannot provide enough energy either for cooking or lighting in rural huts.

Secondly, most of the kerosene is siphoned off for adulteration of diesel because kerosene is much cheaper than diesel (it is highly subsidized by GOI). This results in

the Public Distribution System (PDS) shops not giving it to the poor people since PDS shop-owners make more money by selling kerosene in black.

For our project we got special permission from the Collector of Satara to give an extra quota of kerosene to the beneficiaries but that dictat was continuously flouted by the lower staff and PDS shops on one pretext or another with the result that the poor hut dwellers never got the enhanced quota. This has limited the use of these devices in these unelectrified huts.

I wrote about this to the powers-that-be and also wrote an article on the whole issue of kerosene for rural poor.[38] This article was picked up by the press and syndicated all over the world. I feel that it may have had some effect because now the Government of Maharashtra has opened up the kerosene sales at least on paper. Hopefully this will ease the availability of kerosene to poor people.

We believe that the present total kerosene consumption in India, if used through our lanstove, has the ability to provide a quantum jump in the quality of life of around 180 million people. Unfortunately GOI is phasing out kerosene completely and so we have modified our lanstove to work on diesel- which is available everywhere in the country. Diesel lanstove is even better than kerosene lanstove in terms of combustion and efficiency. We are now actively making efforts to sell this lanstove technology to interested entrepreneurs.

Clean Water Initiative and Rural Restaurants

When we started our work on testing ethanol lanstoves in rural huts we saw that one of the biggest causes of diarrhea and bad health of these hut dwellers was their use of dirty drinking water. We therefore embarked on a small program of developing a simple and low cost technology for sterilization of water using our lanstove.

By filtering the dirty water through four layers of cotton saris or eight layers of synthetic saris (the type normally worn by village women) and then heating the water to 60°C for 10-15 minutes, we were able to completely deactivate all the coliforms

from the water and make it fit to drink.[39] The details are given in Chapter 5. An article on this was syndicated worldwide.[40]

Thus our lanstove not only gives excellent light and cooks a complete meal for a family of five but also makes water fit for drinking. We feel that no single device presently available can do all these three things simultaneously.

Future Research Areas

We also found that most of the women who work as farm laborers come home very tired after working in the sun the whole day. They neither have the energy nor the mood to cook. Besides, they buy rations on a daily basis from the PDS shops, which often do not have adequate rations in stock. The amount and quality of food that these people are forced to eat leads to malnutrition and subsequently to poor health. We developed a concept of rural restaurants[41] where it is proposed that the poor get subsidized meals and the GOI provides good financial incentives for running and starting them. A paper[41] on it was syndicated and published all over the world and we feel may have inspired the concept of 'Amma kitchens' in the southern city of Chennai.

While working with these poor hut dwellers we realized that most of them possess mobile phones and because of non-availability of electricity have to travel 10-15 km to the nearest town to charge them. For them, these phones are not only a means of communication but also entertainment. The hut dwellers listen to music on the radio and some enterprising ones also watch movies on the tiny screen. We felt that with a suitable low-cost thermoelectric device (TE) attached to the lanstove we should be able to charge these phones. This is a challenge which needs to be taken up.

Another challenge is to provide a low-cost refrigerator and a fan. Quite a number of hut dwellers do not have goats and hence they buy milk for tea. The leftover milk gets spoilt unless it is heated repeatedly. This is wastage of fuel. They also cook only once a day and need to store the leftover food. Thus a small low-cost refrigerator will go a long way in improving their quality of life.

Similarly, an efficient fan which moves maximum air with minimum power so as to maximize m^3/W would provide excellent comfort cooling in rural huts. Both the fan and the refrigerator can run on TE devices which convert heat directly into electricity. The challenge is to develop very efficient TE systems. Small refrigerators running on absorption principles which require heat to run them can also be developed.

Still another challenge is to produce biogas economically and very efficiently from agricultural residues[42] and to store this gas just like LPG at moderate pressures in a suitably designed gas cylinders. Development of such a technology can revolutionize rural cooking and lighting.

Some futuristic ideas for household energy are:

1. Identification of a molecule which will dissociate into two with solar energy and when combined later on produce light.
2. Duplication of firefly principle of producing light. Thus chemical energy of molecules is directly converted into light.
3. Production of a material which will combine photovoltaic and Peltier effect to produce direct cooling and electricity by solar energy. It may be possible that energy from solar photons and heat from the room may combine to put the electrons in the device from valence band to conduction band producing both electricity and cooling.

Finally, we should realize that the rural poor do not have a single neuron less than any of us; with their aspirations fuelled by the mass media they too want to improve their quality of life. This can be done by developing and providing suitable devices for the household. I feel the mantra of rural development should be **'Improve the quality of life one hut at a time'**. It is a great challenge to all engineers and technologists and if we can take this up then not only would we have helped create a great India but also helped $1/5^{th}$ of mankind.

Team members

1. Solar distillation of ethanol: Anil K. Rajvanshi, Rajiv M. Jorapur
2. Noorie lantern: Anil K. Rajvanshi, Sudhir Kumar

3. Janata Cooker: Anil K. Rajvanshi, M. S. Joshi
4. Alcohol stove: Anil K. Rajvanshi, Yusuf Shaikh, S. M. Patil, and B. Mendonca
5. Alcohol lantern: Anil K. Rajvanshi, S. M. Patil
6. Kerosene lanstove: Anil K. Rajvanshi, S. M. Patil, K. S. Jagtap
7. Soot measurement device: Anil K Rajvanshi, Etienne Gayet (French intern), and K.S.Jagtap

These members were ably assisted by our technical staff of D. B. Jadhav (deceased), A. M. Pawar, D. B. Gadhave and R. S. Bale. Innumerable foreign interns[12] have helped in lanstove projects since 2005.

Funding from Advisory Board of Energy, MNRE (formerly DNES), DST, ICAR – all Government of India departments and ministries, is gratefully acknowledged.

Biomass Gasification

When I came back from the U.S. in 1981 to live in Phaltan – a sugarcane-growing area in western Maharashtra, my first impression of the area was seeing the night sky lit up with fires! All the sugarcane farmers, after harvesting the sugarcane crop, would burn the sugarcane trash (leaves left after harvest) in the field in a commonly accepted method of waste disposal. Not only was this a tremendous waste of energy but the burning also polluted the clean rural air. There are estimates that this open field burning of agricultural residues produces brown haze over the Indian subcontinent and maybe responsible for weather modification in this region. Hence I thought about what could be done to produce useful energy from sugarcane trash (mostly consisting of dried 0.3-0.5 m long leaves).

Power for water pumping was a major necessity in rural areas and in those days the use of 5 horse power (HP) diesel pump sets all over the country was in vogue. So, the question was how to use the energy of sugarcane leaves for pumping water. There were many competing technologies for this and I developed a method of evaluating them based on the Energy Index (EI)[43] concept.

EI is basically a ratio of the total amount of energy produced by the device in its lifetime to the sum of total energy used in its manufacturing and the energy consumed in running it during its lifetime. Hence the higher the EI the better is the technology energy wise. Producer gas-based units had the highest EI and hence we focused on developing biomass gasifiers.

A biomass gasifier is a device which converts dry biomass (wood, leaves, twigs, etc.) into high quality producer gas[44] (a mixture of carbon monoxide and hydrogen). This is achieved by burning the biomass with less oxygen in a suitably designed reactor. The producer gas so produced contains tars, char and fine dust and hence after being

cleaned with suitable filters can be used to produce electricity via petrol and diesel engine gensets. The cleaning of the gas is very difficult, costly and requires elaborate filters. In case it is not suitably cleaned (which is the case most of the time) then the gas can be used in burners for thermal applications like fuelling furnaces and boilers.

During my U.S. days I had interacted with one Professor John Goss at University of California, Davis. He and his students had developed the first open-top, throat-less rice husk gasifier. In this type of gasifier the biomass is fed into the reactor (basically a metal tube and hence the name throat-less) from the top; it is combusted inside the tube, resulting in the production of the gas. I thought that sugarcane leaves could also be gasified in a similar gasifier.

In 1983 I wrote a small proposal for developing small sugarcane leaves gasifier and submitted it to the Department of Non-Conventional Energy Sources (DNES), Government of India, which was the predecessor of the present-day Ministry of New and Renewable Energy (MNRE). The director of DNES told me that when even large organizations like the Indian Institutes of Institute of Technology (IIT) and Indian Institute of Science (IISc) had not been able to gasify loose leafy biomass, how would a small one like NARI, with very little resources, be able to do it? He suggested I focus on wood instead. He told me to convert the sugarcane leaves gasification proposal to one with a small-scale wood gasifier running a 5 HP diesel engine.

NARI's first gasifier. 1984-85

In a way this was a good suggestion because in developing this gasifier we gained lots of experience; it also allowed me to assemble a good team for our future work.

Our work on the wood gasifier started in 1984. In fact we were among the pioneers of gasification in India. Five groups were given funding for gasification research in 1984 by DNES - IIT Delhi, IIT Bombay, IISc Bangalore, Ankur Scientific in Baroda, and NARI. Ours was the only group with very limited fabrication facility, and raw,

inexperienced staff. Yet, with dedication and by continuously working on the gasifier problems we gained valuable experience.

Meanwhile, in 1986 I also wrote a chapter on gasification in a book published by CRC. In it I wrote about the basics of gasification science and technology and included a section on the status of technology worldwide in 1986. The book acts as a primer for the people who want to learn about gasification and is one of the most quoted biomass gasification books on the internet.

For gasification systems to become successful it is necessary that the producer gas should be made completely clean so that the diesel or petrol engine can run on it continuously for at least 5,000 hours without the need for cleaning and overhauling.

However our work in small-scale wood gasification showed[45] that it was extremely difficult to cool and clean the gas. This is primarily because the tar, which contains more than 200 different chemicals, is difficult to remove with the help of only a few solvents. And secondly the very fine dust in the gas mixes with the tar to make a gooey mixture which gums up the filters and engine intake valves. This necessitated continuous cleaning of the engine. I feel that even today the problem of cleaning the gas persists and has not been satisfactorily solved in any gasifier sold in the market.

Nevertheless we persisted in our efforts and spent quite a lot of effort and time on cleaning the gas from our small scale sugarcane leaves gasifier and ran a 15 kVA diesel genset on it for almost 1000 hours [46]. However the gas cleaning system itself required constant maintenance, resulting in downtime of the system and thus was not user friendly. We therefore decided that the best course of action would be to develop sugarcane leaves gasification technology for thermal applications only.

We also made a conscious decision that for low-density loose leafy biomass material like dry sugarcane leaves the best way to gasify them would be to run the gasifier in pyrolysis mode (running at gasification temperatures of <900°C). Also the biomass input and char removal was done continuously. This allowed the biomass to flow smoothly inside the reactor and without clinker formation.

By the early 1990s we had gained enough experience regarding the issues of gasification and in 1991 I presented a paper at the annual gasification workshop in Vadodara[47] outlining what needs to be done in gasification research in India. The call was to do more R&D in improving gasification efficiency, cleaning of the gas and in producing liquid fuels from biomass. Unfortunately little progress has been made in gasification in India and the issues outlined in that paper are still relevant today.

L-R: D.B.Jadhav, A.M.Pawar, S.M.Patil, D.B.Gadhave, Rajiv M. Jorapur. Photo taken in late 1993.

Our work in sugarcane leaves and other leafy biomass gasification started in 1987 and culminated in 1997 when we developed a 500 kW thermal gasifier with funds from the Rockefeller Foundation. The work started with a one meter tall 15-20 kW thermal gasifier and the final design of a 500 kW thermal gasifier was the 4th generation unit. But then I am getting ahead of my story.

The icing on the cake for our work was when one of the leaders in gasification technology, a professor from IIT Delhi, came and saw our work on sugarcane leaves gasifier in 1992 and said that we had done what all the IITs and IISc could not do. In fact there are good indications that quite a few institutes went on to copy our design in later years!

The reason we were able to achieve success in our design was not because we were more intelligent than the rest – it was purely because of hard work. We continuously modified, changed and tested every component of the system till we were successful. Though we were a small rural NGO with very limited resources we were able to develop the first such gasifier in the world because of excellent team work.

Also in all our gasification and other work we used very simple equipment and in some places improvised on the existing ones to get good data.

For example we set up online an inexpensive Junkers Calorimeter to measure the gas quality continuously. A more fancy and costly equipment of on line Gas Chromatograph with calorific value analyzer could have done the work easily but to maintain it and service it in rural environment would have been quite difficult.

Similarly we developed very simple filters to measure the particulates in the gas by going to the basic science of measuring the gas flow rate and the amount of particulates deposited on a filter. This gave us very good idea about the loading of gas and effectiveness of our filtering system.

Too often I have found that scientists buy fancy equipment which is hardly used and also it is necessary to have a fully qualified technician to use and maintain it. Thus in lots of labs very fancy and costly equipment sit on the desk as showpiece and is used rarely.

I believe that with simple equipment one understands fully well what one is measuring and the limitations of the measurement process. A fancy equipment masks the limitations and also needs constant calibration. This does not mean that we should not use sophisticated equipment but then the user should know thoroughly what the equipment is capable of measuring and its limitations. Today most of the research workers do not have the time or the inclination to do so.

We presented our work on sugarcane leaves gasifiers for electricity generation[46] in May 1992 when I was invited to the third European Biomass Energy Conversion Conference held in Interlaken, Switzerland.

It was a small conference with around 100 participants but almost all the who's who of the world in the area of biomass energy were there. I was the only Indian there. This conference gave me an exposure to the latest work in biomass energy conversion and I was introduced to the technology of pyrolysis oil production from biomass. Basically it involves combusting the biomass in even less oxygen than needed for gasification and then to condense the ensuing gases to produce the oil. This pyrolysis oil is similar to diesel and with suitable modifications and processing via catalysts can be converted into automobile fuel.

In 1992 this was a very new technology and all the people (only three groups) involved in its R&D in the world were present at the conference.

I saw a tremendous opportunity for India to produce its own oil from biomass. I had lengthy discussions with the developers of the technology and they said that they would transfer all the intellectual property rights to an Indian entity at a lump sum cost of quarter of a million dollars. For a country like India this money was peanuts.

I came back from the conference all charged-up, and discussed the whole issue with DNES officials, but got a very lukewarm response. It seemed they did not understand the technology and its implications. So, in desperation and youthful exuberance I wrote a five-page letter to Mr. Narasimha Rao, the Prime Minister of India at the time. Mr. Rao was well-known for never replying to letters even from his closest colleagues let alone from an unknown Indian from the rural area, and hence I wasn't really hopeful about receiving a response. Yet, within 20 days I got a personal letter from him thanking me for bringing the issue of pyrolysis oil technology to his attention. The letter also mentioned that he was sending it to DNES for further action.

Immediately I got a letter from DNES asking why I had approached the Prime Minister! They informed me that this was an old technology that they were aware of and even had R&D projects on! All of this was not true and hence nothing came out of my suggestions.

I felt India lost a tremendous opportunity to develop a national program on pyrolysis oil from agricultural residues. Today, production of pyrolysis oil world over is an important part of renewable liquid fuels, the technology is proprietary and the technology transfer fees are very high.

Finally, just two years ago, MNRE woke up to the potential of this oil and for the first time put out a request for proposal (RFP) for developing a pyrolysis oil program. We thus lost 20 years in developing this technology!

Pyrolysis oil and gasification are closely related and I felt if we had introduced a national program in pyrolysis oil 20 years ago, it would have also strengthened the gasification program, which is now floundering.

Based on our work on a small scale sugarcane leaves gasifier, the Rockefeller Foundation, New York gave us a grant in 1993 to develop a thermal gasifier for industrial application. The idea was to replace the furnace oil based furnaces and industrial heaters by the gas from this type of gasifiers. Taking the actual industry requirement into consideration, we decided to develop a sugarcane leaves gasifier of 100-500 kW (thermal) capacity. Till that time our biggest gasifier was a 70-80 kW (thermal) unit and to scale it up to 500 kW was quite a task.

Sugarcane leaves gasifier at NARI. 1996

Nevertheless the team took up the challenge and in two years we developed our first model of automated and PLC-controlled 250 kW (thermal) gasifier. [24] It was a great achievement and after successfully testing it in a Pune-based company manufacturing ceramic tiles, we scaled it up to a 500 kW (thermal) gasifier, which is presently at our campus. Rockefeller Foundation also told us that this was the first time they had given a grant to an NGO in India and we felt justifiably proud to be so honored.

This multifuel gasifier[24] (it ran on loose sugarcane leaves, sugarcane bagasse and other low density biomass) not only produced useful thermal energy via the production of gas but also produced char (25% by weight of biomass). We used this char in the fields to gauge its effect on crop yields. Today the use of biochar in farming is common, but I think our work in 1993 was the first serious attempt anywhere. A photograph of our work on biochar graced the cover of the prestigious International *Journal of Biomass and Bioenergy (Vol 13, No. 3, 1997)*.

Gasifier powered syrup making furnace, 1995

We also used this gasifier to run our sweet sorghum production unit.[48] This showed that gasifiers can be used for large scale community cooking provided the gas burners are in well ventilated areas. Producer gas contains about 10-15% carbon monoxide (CO) - a lethal gas. Hence the burners should be in ventilated areas so that the cook is not exposed to this gas. We also developed small ruminants (sheep) disposal units using the gasifier and were able to burn one dead sheep in under an hour. We feel that biomass gasifiers maybe used in future for human and animal cremations.

One of the major issues in developing loose leafy biomass gasifier was the transport of low density biomass from the fields to the gasification unit. To reduce the transportation cost we felt that biomass needs to be compacted. In those times (early 1990s) there were no baling machines available in India. So we discussed with the farm machinery manufacturers in India a need to develop such machines but they were not interested because they did not see the market. Importing a machine from abroad was very costly. Even today there is a great challenge to develop baling machines for agricultural residues since these residues are becoming an important resource for power generation and composting.

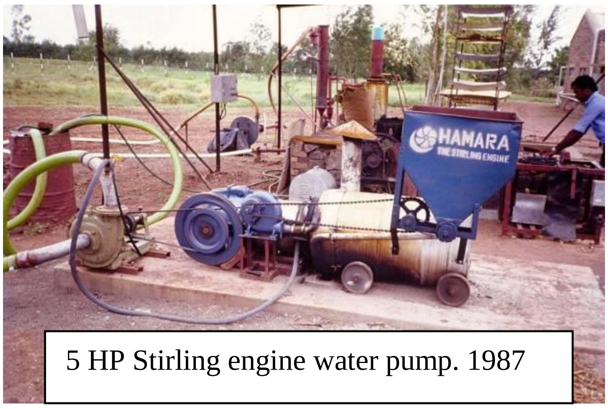
I believe we were very successful in designing and developing the sugarcane leaves gasification system for thermal applications. However our failure was that we were not successful in marketing it. One of the reasons was that we were almost 10-15

years ahead of time; in the late 1990s very few people were interested in it. And secondly it was not economically viable in those times. Now with increasing oil prices and shortage of electricity in India there is a renewed interest in providing thermal and electricity options from locally available biomass resources. Thus there seems to be a renewed interest in thermal gasification systems in India and worldwide and we get regular inquiries about our gasifiers.

However I still feel that even now the biggest challenge is how to efficiently and thoroughly clean the gas for power generation. This is an area that R&D in gasification work should focus on.

Though we did lot of work on biomass gasification another attractive technology for motive power in rural areas is stirling engine[49]. Stirling engines are external combustion engines in which heat from any source can be used to run them. Mostly their working fluid is air. Their efficiencies are poor and though they were invented almost 120 years ago, have never reached their full potential. The main problem has been with the design and materials of heat exchanger which has to rapidly transfer heat between hot and cold cycle.

I was familiar with their design and working since our lab in University of Florida was well known for its work on solar powered stirling engines. So when in early 1980s we were gifted a "Hamara" stirling engine by Maharashtra Energy Development Agency (MEDA), I eagerly looked forward to testing them. This engine was manufactured by a party in Madras (now Chennai) under license from Sunpower Inc – a US based company.



5 HP Stirling engine water pump. 1987

The simple "Hamara" engine (pictured) had efficiency of only 1-2%, was very heavy, expensive and costly to run. That was the main reason why it never took off despite its attractive feature of running on any heat source.

Recently there are indications and claims by some manufactures that with new materials and manufacturing technology (3D printing) for making heat exchangers, their efficiencies have improved. However only time will tell whether these claims will stand in the market place.

Future research areas

1. Most of the issues for future R&D in gasification were discussed in my idea paper given in 1990 at Vadodara.[50] Those issues are still valid. Basically they are cleaning of gas and making small continuous gasifiers.

2. Besides gasifier there are many streams through which agricultural residues can produce energy. Biogas reactors or digesters are one such route. They can produce methane from fresh residues to drive internal combustion engines and the slurry from the digester is an excellent fertilizer for the soil. Increasing fertility of the soil is one of the main activities of farming. The fertility can also be increased by incorporating the agricultural residues directly in it or by composting them. However in that process precious methane is lost to the atmosphere and cannot be used as an energy source.

   The challenge is to produce very efficient and continuous biogas digesters running on agricultural residues and design engines to run on them. Existing diesel engines are quite suitable to run on biogas but require improvements to increase their efficiencies.

3. For producing high quality energy there is a challenge of converting agricultural residues to liquid fuels like petrol and kerosene. These can power the existing internal combustion engines for rural mobility, farm machinery and electricity generation.

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Taluka Energy Plan

In March 1986, Mr. Sharad Pawar, the former Chief Minister of Maharashtra and at that time leader of Congress (S), arranged a major conference in Mumbai to develop future strategies for Maharashtra. I was invited by the organizers to present my view on the future strategy on energy.

This conference was inaugurated by the Prime Minister Mr. Rajiv Gandhi and for three days very active deliberations took place on a whole horde of issues including urbanization, water conservation, unemployment and energy, among others. Though the who's who of Maharashtra very actively contributed ideas for solving the problems of the state, this conference had a political agenda and so nothing came out of its deliberations!

My major thesis, in the paper presented,[51] was that through biomass (either agricultural residue or that specially grown for energy) we could produce all the energy needs, including electric power, for a taluka. The thinking behind the taluka plan was that small villages did not have the financial and administrative power to provide energy and hence were a drain on resources; on the other hand, big cities were so big that biomass-based power plants could not fulfill their energy requirements. Thus a taluka administrative block with biomass available locally provided a nice 'middle path' approach to the development model and energy solution.

We also believed that the Taluka Energy Plan could be a step towards developing a decentralized energy strategy for the country. Both these ideas were quite revolutionary at that time and had not been thought of in the Indian context. Now there is a good deal of talk about using decentralized energy strategies and making the taluka a focus of development for rural areas. Our strategy of making a taluka the unit for development came out of the data we had gathered on the energy needs of Phaltan taluka.

I used to regularly give lectures in the Mechanical Engineering Department of the Indian Institute of Technology (IIT), Bombay. Aziz Lookman, a first year B.Tech. student who attended my class, wanted to do something useful and meaningful during his summer vacation. He came to our Institute in the summer of 1984 and was our first intern! I gave him the project of collecting data on energy use in Phaltan taluka. In the 40^{o}C + heat of summer in Phaltan he would bicycle all over the town, going to government offices and petrol stations to collect data on how much electricity, petrol, diesel and kerosene the inhabitants of Phaltan taluka consumed.

This to my knowledge was the **first energy data collected for a taluka in India** and paved the way for the detailed survey that we did in 1990. Based on this data we developed a strategy for replacing fossil fuel-based energy like petrol, diesel, LPG and electricity with renewable energy. This led to our thesis on biomass-based power plants.[51]

Biomass-based power plants are very similar to the regular coal-fired plants; the only difference is that instead of coal as fuel they use biomass which consists of wood and agricultural residues. Since the biomass has different density and energy than coal the fuel handling and combustion part of biomass power plants slightly differs from that of coal.

Research and letters from my U.S. contacts also showed that that U.S. was active in this field and that a 1-2 MW biomass-powered plant had been installed in the Philippines by a U.S. company as a part of a USAID project.

I requested the Department of Non-Conventional Energy Sources (DNES), Government of India (GOI) to fund a possible trip to visit this plant in the Philippines, and extend this concept of biomass power projects for India. In 1986 a two-member team comprising of Dr. K. S. Rao, Director of Gujarat Energy Development Agency (GEDA), and myself was sent to the Philippines and Thailand, as FAO experts to study their biomass programs. Besides visiting the power plant we had to look at their biomass gasification programs, briquetting, and biomass-

powered stoves. It was quite an educational trip and showed that South-East Asian countries were ahead of India in the use of biomass energy.

The power plant in the southern part of the Philippines was in quite a rundown condition and had been shut down. While the official line was that adequate biomass was not available, the main reason was that it was in an area heavily infested by Communists and nobody wanted to work there. Anyway, it gave me some idea on what a biomass-based power plant looks like. We wrote a detailed report on our visit to DNES with the specific recommendation that India should set up an experimental 1-2 MW biomass-based power plant. Nothing came out of this recommendation.

In 1987, I went on an extended (self-funded) U.S. trip and had made plans to see the biomass-based power plants in California. In the late 1980s California had biomass-based power plants of 6000 MW installed capacity – the largest in the world!

I identified a party called Yanke Energy from Idaho who had set up a couple of biomass-based plants in northern California and went to visit them. Their chief engineer, Mr. Shultz, and I became good friends and he gave me a complete tour of his plants, including the detailed drawings and design of the 10 MW units.

Armed with this information, I approached the chairman of the local cooperative sugar factory on my return to Phaltan, and suggested that besides producing sugar, he could easily make his factory into a power plant. He wasn't interested in the scheme at all and wanted to know what was in it for him! This was in 1987 and far ahead of the time when cogeneration in sugar factories became fashionable in the late 1990s.

In fact, most of the cooperative sugar factories in Maharashtra have been used for political purposes to provide money for fighting elections. This siphoning off of funds is the main reason why these factories have become sick and very few of them are solvent today.

I then prepared a small note on biomass power generation in Maharashtra and sent it to Mr. Sharad Pawar, who was at that time the leader of the Opposition in

Maharashtra. He passed on the note to the Chairman of Maharashtra State Electricity Board (MSEB), who replied that it was the most ridiculous scheme he had seen and that MSEB would collapse if it had to take energy from small power stations of 10 MW each! I guess this was a reflection of the dinosaur mentality among electricity officials who had not understood the power of decentralized energy production. Anyway, nothing seemed to be moving though I was convinced of the merit of this strategy.

10 MW biomass power plant in California, 1990

When an opportunity came in the form of an ICICI-based PACER project which was funded by USAID, I wrote a proposal for a full study on biomass-based power plant for Phaltan taluka. In this study[52] we carried out a detailed mapping of the agricultural residue available in Phaltan taluka and then went to the U.S. for a comprehensive study of the biomass power plants. Our study showed that Phaltan taluka had enough agricultural residues available to produce 10-15 MW power year round, and one of the recommendations was that a similar study of biomass availability should be done for all the talukas in the country.

After the study, which we finished in the middle of 1991, we arranged for a small workshop[52] to evaluate, debate and discuss the findings. We invited Dr. R. K. Pachauri from Tata Energy Research Institute (TERI), Mr. B. B. Vohra (former Chairman of Advisory Board on Energy), and officials from MSEB, DNES and ICICI, among others. One of the key recommendations was that a few such power plants be established in different talukas. However, in the absence of funding it was difficult to see why anybody would want to set up such plants and thus this concept remained on paper.

In 1994 I presented a paper on the taluka energy concept at an international conference in Bangalore. This paper was picked up by the mass media, and a report appeared in the Indian Express, which was probably read by somebody in Prime

Minister Narashimha Rao's office (PMO). A high-level task force was set up by the Ministry of Non-conventional Energy Sources (MNES) in late 1994 to evaluate this concept and, if found feasible, to set up a national policy. I was invited to be a member of this task force and present our findings to the committee. Before the first meeting of this task force took place a very senior official in MNES asked me how I knew the Prime Minister since this task force had been set up on the suggestion of the PMO. When I told him that I did not know him at all he was quite surprised but arranged for my meeting with the Minister of MNES at his house.

After the task force meeting ended I went to see the Minister, who asked me the cost of the project for a taluka. I gave him a rough estimate of Rs. 100 crore per taluka. He told me that I should immediately fax him a two-page proposal to set up the power plant and all the necessary funds would be given. When I told him that we still had to deliberate the issues in the task force and then take up the matter of setting up a power plant on a trial basis, he did not seem very happy. I got the feeling that he wanted a cut from the money meant to set up the power plant. Later I heard that he and his family were indicted for corruption!

In late 1995 MNES announced the national policy on Taluka Energy Plan.[53] We felt very proud that a small NGO working on a shoestring budget could be a principal author of a national policy. Later, a very senior ICICI official told me that this was the first time in the history of ICICI that a small project (our PACER project in 1990 was for Rs. 3 lakh only) had led to a national policy! We also feel that this taluka plan might have helped in formulating the national program of Provision of Urban Amenities to Rural Areas (PURA) in 2003.[54]

The Taluka Energy Plan envisaged that private players could set up 10-15 MW biomass power plants and MNES would give financial help both for setting up the plants and developing a biomass atlas for each taluka in the country. However, this was before the new Electricity Act which came into existence only in 2003. Thus, no entrepreneurs were interested in taking this up since they would have had to deal with the loss-making State Electricity Boards.

Finally when in 2003 the new Electricity Act was passed by Parliament and the laws allowed anybody to produce power and sell it, biomass-based energy power projects picked up. This was also facilitated by generous financial help from the Indian Renewable Energy Development Agency (IREDA), New Delhi.

As of today around 120 biomass-based power plants each of 6-10 MW capacity have been installed all over India. These are in addition to the cogeneration-based power plants in sugar factories.

10 MW Biomass Power Project, Gadchiroli Distt. (Maharashtra State); Courtesy MNRE

Besides setting up the power plants, Ministry of New and Renewable Energy (MNRE) also asked all the state energy development agencies to develop the biomass energy availability map for each taluka. Funding was also provided to various agencies to develop a national biomass atlas. This was again based on the protocol that we developed in 1990 for our Phaltan study.[52]

Finally, it should be pointed out that India produces 600-800 million tons of agricultural residues in its talukas. Theoretically this biomass can produce nearly 70,000 to 80, 000 MW of electricity year round. Thus, agriculture can not only produce food but also power[55] and the Taluka Energy Plan has a great potential of easing the energy situation of India, provided very liberal economic incentives are given to the power producers.

Future Research Areas

1. Besides the Taluka Energy Plan, a simpler solution for rural electrification could be based on the demands of each village. Our data showed that 500 kW electric power for each village[56] could take care of the household and agricultural energy demands. Such power plants can also produce potable water.[57] The challenge is to produce this power through renewable energy sources like solar, wind or biomass. Thus, development of economically viable technologies and solutions will help in rural electrification.

2. There is also a need to develop low temperature (~ 70-90ºC) solar thermal power plants. These could be in the range of 100-200 kW and run on organic Rankine cycle.[58] Presently, power generation from solar energy suffers[59] because it cannot produce power during night. Organic Rankine systems running on 70-90ºC solar-heated water can easily overcome this problem by storing the hot water for night operations. The challenge is to identify suitable organic liquids and to develop leak proof systems. Though the efficiency of these systems will be low, the ease of operation can offset the efficiency handicap.

3. For biomass-based power plants there is a challenge to develop agricultural residue baling and compaction machines. These can reduce the volume and cost of transportation of biomass to the power plant. Such machines do exist but those powered by fuel produced from farm or even electric power need to be developed.

Publications of NARI on Taluka Program

1. Anil K. Rajvanshi, ‘Energy Self-sufficient Talukas – A Solution to National Energy Crisis’[60], Economic and Political Weekly (EPW), Vol. XXX, No. 51, Dec. 23, 1995. pg. 3315-19.
2. Anil K. Rajvanshi, ‘Talukas can provide critical mass for India’s sustainable development’[61], Current Science, Vol. 83, No. 6, 25 September 2002.

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Electric Rickshaws and Farm eMachines

When I was growing up in Lucknow during the 1960s I used to regularly ride on the cycle rickshaw. Anytime the rickshaw went uphill I would get off and push it! To my young mind the idea of one human being engaging in hard physical labor to transport another was quite shocking and horrifying. Yet, that was the only mode of transport available in those days and, whether we liked it or not, we had to use it.

When I was studying at IIT Kanpur none of the professors ever challenged us to improve the cycle rickshaw – the projects in the late 1960s were focused mostly on U.S.-centric problems! So, after my return from the U.S. in late 1981 I decided to take up the challenge of improving the cycle rickshaw. Such improvement had no significance in Western Maharashtra where these vehicles were banned on humanitarian grounds in the 1960s by Mr. Morarji Desai, who was at that time the Chief Minister of Greater Bombay.

However, I was keen to improve the cycle rickshaw for another reason. Starting in 1981, everyday for almost two years, my wife and I would cycle back and forth from our home to our Institute two times a day for a total distance of 12 km. The bicycle was my only vehicle till my younger brother took pity on me and donated his scooter in 1983. The tarred road on which we cycled was lined on both sides by thorny *Acacia* and *Prosopis* trees. Not only did these trees provide shade to the road but also thorns, which regularly punctured the tires!

Data collected from our staff members (all of them came to work on bicycles in those days) and our own experience showed that 73% of the total maintenance cost of a bicycle was tire-related. Besides, it was difficult to go uphill and against the wind on a bicycle. I therefore started to think about how to improve the cycle and felt that any improvement in bicycle design will have bearing on the rickshaw design as well.

Literature on bicycles revealed that one Dr. David Wilson, a professor of Mechanical Engineering at MIT, Boston had written a bible on bicycle science and was the originator of the recumbent bicycle. This is the type of cycle where the driver sits in a reclining position and uses his leg muscles efficiently like that used while rowing. I

corresponded with him and we became good friends. I thought of incorporating some of his ideas on recumbent bicycle design into rickshaws. Data on energy use in various transportation systems also revealed that pedal power was the most efficient mode, consuming the lowest energy per unit mass transported.

In 1983 I put all these ideas together in a note on the strategy for improving the cycle rickshaw[62] and sent it to Mr. H. N. Bahuguna, who was the former Chief Minister of U.P. and an active Member of Parliament. He had started his political career as a leader of the rickshaw-pullers' union in Allahabad, and the cause of the rickshaw was very close to his heart. He immediately put up a non-starred question in Parliament, asking the Government of India (GOI) about the status of rickshaw improvement in India and whether the GOI was aware of the work being done at NARI. Naturally the Ministry of Transport wrote that quite a lot of work was being done by various GOI organizations; but this was not true.

Since no cycle rickshaw was available for study in western Maharashtra and I also got involved in setting up the lab at NARI for work in solar distillation[19] and gasifier development[63], the work on rickshaw improvement took a back seat.

However in 1995 (almost 11 years after I had written the note), I decided to attack the problem seriously. The incentive to do so came from the desire to develop electric cycle rickshaws. New developments in battery-powered vehicles world over gave us on opportunity to use that technology for cycle rickshaws. I also thought that since rickshaws provide last mile connectivity, are small enough to go into small lanes and provide huge employment opportunities for rural and urban poor, an environmentally sound electric cycle rickshaw will be a boon for the cities and small towns.

In 1993 I had gone to Atlanta, U.S.A. to present a few papers at the International Energy Conversion Engineering Conference (IECEC). There I met Henry Oman[64], a distinguished electrical engineer[65] who had retired from Boeing Corporation. He presented some interesting work on electric bicycles, which I believed could have implications for cycle rickshaws.

After the conference we corresponded and during my next U.S. visit in 1995 Henry invited me to visit him in Seattle, Washington. There he and two other retired colleagues from Boeing Corporation had set up a small company to do R&D in electric bicycles. For three days we had brain-storming sessions on how their work could help in developing an electric cycle rickshaw. We also prepared a business plan for development of special electric motors for rickshaws and submitted it to the Rockefeller Foundation. However it was not funded because Oman and his friends were asking for too much money for their part of the project.

This visit also gave me an opportunity to visit Seattle's lovely downtown waterfront area, very popular with tourists. I saw a handsome blonde guy driving a cycle rickshaw (called a pedicab), which I discovered was imported from a South East Asian country. I befriended him and asked the cost of a ride. He said it was $15 for a one-km ride on the waterfront. He also told me that the money he earned by riding the rickshaw helped pay for tuition at a local management school.

When I questioned him about the high cost of the ride, he replied it was $5 for the effort and $10 for the scenery! Very helpfully he explained that most of his passengers were females working in the IT industry, and the scenery referred to the very short shorts he wore! Being an MBA student he had figured out his strategy quite nicely!

Anyway, that gave us an idea - if we could design a good cycle rickshaw for India it could also be sold in the U.S. and Europe as a tourist vehicle! Later we did export about two dozen of our improved and electric cycle rickshaws to Europe and the U.S. where they were indeed used as tourist vehicles.

In the meantime, in 1995 we got a small project from E & Co., a New Jersey based renewable energy investment company, to do a detailed study on rickshaw improvement for India. Our work on mobility was therefore initiated by the grant from E & Co and we were grateful for their vision. Unfortunately E & Co wound up in 2011.

We did a detailed survey in Lucknow (where my parents were still living) on the problems of existing cycle rickshaws. I must have interviewed hundreds of rickshaw pullers and manufacturers for this study and I believe that the final report in 1997 was the first such systematic study on the whole issue of cycle rickshaws.[66] I wrote a short article based on this report which appeared as an editorial article in the Economic Times[67] and elicited tremendous response from readers. I think this article was the first one anywhere about modernizing the cycle rickshaw.

We also purchased a few rickshaws from Lucknow in knocked-down condition and assembled them at NARI to study their performance.

NARI's improved cycle rickshaw. 1996

We then designed a lightweight and easy-to-drive rickshaw[68] and tested it on Phaltan roads. However, converting this improved rickshaw into an electric-powered one proved to be quite difficult, since in those days (mid 1990s) small, high-torque permanent magnet D.C. (PMDC) motors and controllers were not available in India. We hunted for these motors and controllers all over the country because the desire was to have only Indian-made components for the rickshaw.

Luckily in late 1995 we got a very rudimentary e-mail connection. We were probably the first rural organization in India to get this and were able to send and receive short emails but could not surf the web. In fact 1995 was also the year when internet was introduced in India, so we got hooked into the internet revolution right from the beginning. This connection allowed me to send an SOS regarding PMDC motors to my friend Dave Wilson at MIT, who sent me good material on them but mostly from U.S. based companies.

Finally we were able to locate a vendor in Pune who had a small company that made PMDC motors. He expressed great interest in our work and was ready to develop the motor according to our specifications. We bought a few motors from him and tested them on our rickshaw. Based upon the feedback on the load characteristics, he modified the motor to our satisfaction. We also located a gear manufacturer in Pune to design a suitable gear for this motor.

However one of the hardest parts was the design of the controller for the rickshaw. After a fair amount of difficulty we were able to locate a party in Pune to design a simple controller based on the load characteristics. All these efforts finally resulted in the design of our first model of a motor assisted pedal rickshaw (MAPRA). The issue of a low cost reliable controller has however remained unsolved and there is a need for R&D on it.

MAPRA

We lacked any fancy equipment to measure load characteristics of motors. So, armed with only a voltmeter and an amp-meter we measured the actual load every 10-15 seconds while the rickshaw was driven on the rural roads of Phaltan (full of potholes), and were thus able to collect very detailed real time data on load characteristics. In fact, when I gave a talk in 2002 at U.C. Davis Institute of Transportation Studies in California, USA they were quite amazed at the ingenuity of our data-taking device.

This tradition of getting very sophisticated data from simple experiments and equipment has been a practice at our lab.

We tested these MAPRAs on Phaltan roads in the late 1990s. There was a tremendous response from the locals – in fact hordes of onlookers would surround it whenever it went into town. The feedback however showed that very few people in Western Maharashtra wanted a motor-assisted pedal rickshaw (MAPRA); most of them preferred a completely motorized one.

With the help of funding from the Ministry of Non-conventional Energy Sources (MNES), GOI we embarked on the design of an electric auto rickshaw and by 2000 developed the **first electric rickshaw in India**. We christened it ELECSHA and got the trademark registered. We used an American controller since the locally made units were mostly not available and the few which were in the market were not up to the mark.

ELECSHA 2000

ELECSHA (pictured) has been now running for almost 14 years and has logged more than 35,000 km. We use it at our Institute to transport guests and run small errands. Except for occasional battery changes and a few minor repairs, it runs well on rural roads. I feel that with new developments in hub motors ELECSHA can be modified and made more efficient.

I also feel that ELECSHA type vehicles should be made into hybrid ones so that their range can be increased. In a hybrid vehicle a small petrol powered IC engine charges the battery which powers the electric vehicle. Presently our ELECSHA can go to 40-50 km in one charge and a hybrid system can extend this easily to 100-200 km easily. Hybrid ELECSHA can be a great last mile and point-to-point vehicle for urban and rural India.

In late 1999 I presented our work on the improved cycle rickshaw and its conversion to ELECSHA at an International Conference on Electric Vehicles at IIT Kanpur. The paper elicited tremendous response from the participants since this was probably the first attempt in improving the humble rickshaw and making it into an electric one.

I sent a copy of this paper to Dr. David Wilson at MIT who promptly published it in the *International Human Powered Vehicle Journal* published by MIT. A detailed paper on our later effort was published in *Current Science.*[69]

I believe our work at NARI in 'electrifying' the rickshaw in the late 1990s **was the first such serious effort anywhere in the world.** We put all the details of our rickshaw on the internet. Our work was copied by a large number of agencies the world over. In fact quite a number of them copied ad verbatim material from our paper without giving us any acknowledgement. The copying of our design (though patented in India) was a loss for our Institute, but also an indication that we were ahead of time.

Our technical paper was picked up by the press in early 2000[70] and large scale publicity [71] ensued. In my view, the latest electric rickshaws plying in various towns in India can be traced to our original design.

Inaugurated by Madhur Bajaj and Pune VC, Kolaskar

In early 2002 we donated five MAPRAs to Pune University to be used on their campus. The rickshaws were inaugurated with fanfare with Mr. Madhur Bajaj, Vice-chairman of Bajaj Auto and Mr. Ashok Kolaskar the Vice Chancellor of Pune University taking an inaugural ride in them.

The rickshaws worked quite nicely but the University did not want the responsibility of repairing them, despite the fact that they were given free and the University had a full-fledged workshop with technical staff. So, even for a simple thing like repairing a tire puncture or other minor repairs I had to send across our technicians from Phaltan. They also had a problem to get rickshaw pullers since there is no tradition of cycle rickshaws in Western Maharashtra. Hence it was getting to be a headache to manage them from Phaltan. So after a year we took back all five rickshaws and felt sad at losing an excellent opportunity to expand such efforts on a University campus. We tried a similar venture with IIT Kanpur but there too the authorities did not want to take any responsibility; they wanted us to deal with the rickshaw-pullers directly.

We thought of setting up a rickshaw-pullers cooperative society in Lucknow, which has the largest number of cycle rickshaws in the country. This idea was further helped by a Mr. Agarwal from Lucknow who approached us after reading of our efforts in newspapers. In 1999 we signed an MOU with him to manufacture our MAPRA and improved cycle rickshaws and sell them in north India. Though Mr. Agarwal did not have funds, he had connections in the U.P. Government. That is when I learnt that the Central Government gives huge grants and loans to poor members of backward classes and minorities who want to buy rickshaws.

Mr. Agarwal took me to meet the Director of the Minorities Commission in Lucknow. He liked the design of our rickshaw but said it would be difficult to promote them under the Central Government scheme since they were different; he insisted that we convert the existing cycle rickshaws into electric ones. I told him that the existing rickshaws were of a very poor design and converting them into an electric rickshaw would be very inefficient. I also explained to him that this was the reason we had first improved the existing rickshaw and then converted it into the MAPRA!

He was not convinced by my argument and so our meeting was inconclusive. Only when I came out of his office did I realize what he was hinting at! Most of the time the huge funds that came from the Central Government for loans/grants to minorities seeking to own a rickshaw were shown as ‘given’; nobody counted the rickshaws on the road as they all looked the same and were not registered. Our improved rickshaws would have stood out like a sore thumb!

Though the loan was shown as disbursed on paper, it was never given to the rickshaw-pullers; instead it was siphoned off by the politicians and government officers. This fraud was further helped by the fact that rickshaw manufacturing was a footpath industry, hence there was no mechanism for counting their numbers.

Despite this setback I still believed that we should set up a rickshaw-pullers’ cooperative society in Lucknow even if NARI had to pay from its own pocket. I approached the Registrar of Cooperative Societies in Lucknow, who told me that no cooperative society succeeded in U.P. and that I was wasting my time. Sadly, this state of affairs still continues in U.P. and may have even become worse. Our efforts

to introduce our improved rickshaws in Lucknow in the late 1990s thus failed. Now I am told that there are number of efforts to introduce improved and electric rickshaws in some cities of U.P.

In 2001 I also suggested that our electric cycle rickshaws be used in the Taj Mahal area in Agra. All the 5 star hotels in that area liked the idea but they were not interested in the logistics of running the rickshaws. It seemed like everyone wanted us to manufacture the rickshaws and sell them. Nobody was interested in buying our design and commercializing it.

NARI electric cycle. 2001

In the late 1990s we also started work on an electric bicycle just out of interest, and made quite a few models. However the unavailability of a low-cost hub motor, good controller, and low-cost high density battery hampered our efforts. In any case for a few years I had fun testing and riding the electric bike back and forth from my office to home – a total distance of 10 km daily.

In 2002 I was invited by TI Cycles, Chennai – the second largest bicycle manufacturer in India - to help with their electric cycle work. I tried to make them interested in our electric rickshaw but they did not think it was a commercially viable proposition. Their efforts to produce and market electric bicycle failed at the time because of the unavailability of a low cost hub motor.

Due to the current availability of good hub motors and controllers the electric bike program has picked up world over and there are millions of e-bikes across the globe.

The publicity around our work on cycle rickshaws resulted in lots of fan mail. In 2003, a mother from Chandigarh wrote to us, stating that her son was paralyzed from waist down and could we design an electric trike for him.

This set me thinking about the design of a rickshaw for physically handicapped (PH) persons. When I tried to get data on the number of handicapped persons in India, I was shocked to find that it did not exist. Innumerable emails to associations working for the handicapped all over India gave conflicting numbers. Nevertheless we decided to design such rickshaws. To start with we got a PH person from Phaltan and quizzed him about what he would like to see in a good vehicle for the handicapped. Based upon this feedback we designed the final vehicle.

Electric trike

Because of our experience with designing electric cycle rickshaws we designed two rickshaws for handicapped persons.[68] One was a Motor Assisted NARI Handicapped Rickshaw (MANHARA), and the other was a completely automated rickshaw called an electric trike. Both have been given to few handicapped persons.

In late 2008 there was news in almost all mass media of a new cycle rickshaw called Soleckshaw, which was introduced in New Delhi by the Council of Scientific and Industrial Research (CSIR), Government of India. The vehicle looked very similar to our MAPRA and even the name Soleckshaw rhymed with our ELECSHA. Also their publicity photo of Delhi inauguration was almost identical to ours!

I did not pay any attention to this but a journalist friend (a very senior science journalist), who remembered our work on electric cycle rickshaws in the late 1990s, called me in 2010 asking whether I had seen the design of the Soleckshaw. He said it looked very similar to our MAPRA and he wanted the details of our work. I sent him all my previous work including the photographs of our rickshaw and those of Pune University inauguration.

Digging a little deeper it seemed to appear that CSIR may have copied our design. In science and technology, evolution of a design takes place based on the existing work and hence it would have been justifiable if CSIR had acknowledged our contribution but unfortunately they did not. I have found that very often the research community

in India uses ideas and designs from others without proper acknowledgement. I think this is very unprofessional.

In any case the journalist friend wrote a story on the CSIR Soleckshaw and about our work[72] so that the record could be put straight. Nevertheless I am happy that CSIR took our concept further and showed that we were ahead of times.

Since our work in the late 1990s lots of development has taken place in hub motors and controllers and we believe that the issue of developing a cheap electric cycle rickshaw should be explored again. MAPRAs and ELECSHAs can be an excellent last-mile and environmentally sound conveyance system. Just recently GOI has announced help in spreading electric rickshaws all over India. We feel vindicated that our pioneering work started in 1995 has now borne fruit.

Development of other battery powered technologies

Since ours is an agricultural research institute we thought of using battery powered systems for agricultural machines. Our first invention was a battery powered safflower petal collector. Safflower petals can be used as excellent herbal tea. Since safflower is a thorny plant and difficult to handle, we developed a battery powered knapsack type petal collector.[73] This was probably the first such collector system anywhere in the world and has elicited tremendous response. It has been exported to various countries like Iran, Nepal, etc.

Battery powered safflower thresher

To collect research data from small plots we need stand-alone small threshers. Such threshers are available but they run either on noisy diesel engines or on AC electric motors. Therefore for field operations we designed small battery

powered threshers for safflower and sweet sorghum. This could be easily wheeled to the fields.

Future research areas

1. The main stay of rural transport is petrol driven motorcycles. They can be easily displaced by more efficient electric ones which are becoming easily available in the European and American markets.[74] They match the speed and torque of the existing motorcycles and go to a distance of 50-60 km in one charge. Besides they give an average of 200 km/l of petrol equivalent which is nearly 5 times more than the petrol ones. Similarly a unique technology of air motor cycles[75] can be a zero emission rural vehicle. These air bikes are in early stages of development but with rapid strides in their technology may become available at low cost. Thus electric and air motorcycles can in future become the main transport system in rural areas. The challenge is to design them for rural roads, reduce their cost and develop local electric and air charging systems.

2. For rural areas there is also a need to develop hybrid motorcycles i.e. a small IC engine charges the batteries and runs an electric motor. Thus the hybrid motorcycle is basically an electric one. Not only will it allow more efficient running of petrol engine but the system can also be used to provide electricity for rural huts when it is not being used for transport. Rapid improvement in battery technology world over makes this idea quite attractive.

3. Finally there is a need to develop liquid fuels like kerosene and petrol from agricultural residues. These fuels can power the two wheelers and the farm machinery.

Team members:

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Water Related Research

Quite a lot of work described in this document was done by me in 1970s when I was a graduate student and faculty of Mechanical Engineering Department in University of Florida (UF), Gainesville, U.S.A. I feel that quite a number of problems explored and tackled at that time have still remained unsolved and hence my desire to put them down in this article.

Potable water

Sea water desalination

In late 1974 I went to UF to do my Ph.D. in solar energy under the solar pioneer Dr. Erich Farber. Since I was a Government of India scholar with full fellowship hence I was not dependant on UF professors for funds and topics of research. Thus I had the liberty to choose any subject of my choice for Ph.D. work. That naturally put a lot of burden on me.

So when I started my Ph.D. course work in January 1975 the main focus was to find out various areas of research. From my reading of the solar literature it appeared that the best topic would be desalination of sea water using solar energy.

In early 1970s world did not have shortage of water but reading the predictions by some of the leading experts in water convinced me that in future more than the energy crisis, world will suffer from water crisis. And felt that desalination of sea water should be the focus of research.

In my research I also realized that nature has all the answers and hence the best course of action was to follow nature in our design. This was much before the time when biomimicry, as it is called today, became a buzz word.

Nature produces rain from salty sea and hence it is the world's biggest desalination plant. Thus the idea was to duplicate in my design the whole process involved in rain making. Naturally this was a tall order and proved to be very difficult to implement.

Since evaporation of water takes place from the surface of sea, I became interested in the surface phenomenon. Quite a number of courses on surface science which I took at UF showed me that surface acting agents called surfactants (basically soaps) may play a role in enhancing sea water evaporation. I found out that plankton and other biological material found in sea water maybe acting as surfactants. So I did many experiments in chemical engineering lab of Dr. Dinesh Shah on the role of surfactants on evaporation of sea water.

Theory showed that since surfactants help in reducing the surface tension of water they might help in increasing water evaporation. In practice the tight packing of surfactant film on the water surface inhibits its evaporation. In fact the surfactants are used quite often on lakes and ponds to reduce water evaporation.

Evaporation of water under high voltage (1975)

So the idea came to me that if the surfactant molecules at the surface could be perturbed then the water molecules could wiggle through the surfactant layer and evaporate, similar to what maybe happening at the sea-air interface.

In nature this perturbation of surface (production of waves) happens because of wind but in an enclosed environment I thought a better way could be to apply high A.C. voltage field to flip flop the surface. Hence I did quite a number of experiments on the use of high voltage (upto 20 kV both A.C. and D.C.) to perturb the surfactant layer at the surface. Some enhancement of evaporation was seen, but results proved to be inconclusive. Besides, in the enclosed environment of distillation apparatus, the condensing film of water sometimes created short circuits in the apparatus.

The use of high voltage for desalination was also studied because I wanted to duplicate the affect of lightning on water condensation inside my still. Lightning in clouds result because the evaporating water droplets get charged. How they get their charge is still a mystery. Lightning nevertheless helps in rain formation by

accelerating the seeding of clouds. Hence I wanted to create artificial lightning in the still by using high voltage to charge the evaporating water.

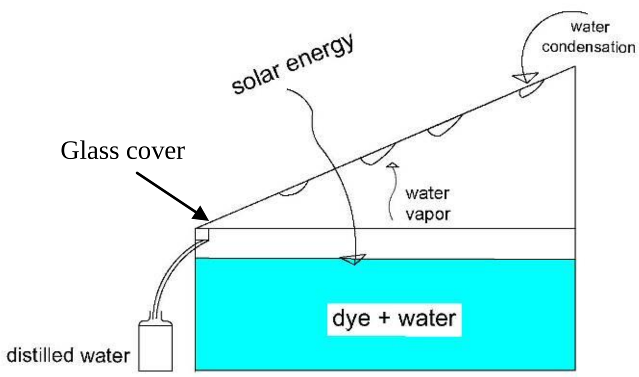
Discussion with Dr. Martin Uman[76]the pioneer of lightning research at UF showed that it was a tall order and I was biting more than I could chew! So I abandoned this line of research.

Nevertheless I became interested in the phenomenon of how evaporating water gets its charge and is transferred to the clouds. This line of research led me to the work of Irving Langmuir at General Electric (GE) who had studied the charge production from an evaporating cup of coffee and had done pioneering work in cloud seeding. Langmuir was a great scientist and the first industrial chemist to get the Nobel Prize. I became so fascinated with his life story that later on I wrote a biographical essay on him[77] which was published in Resonance – India's leading journal. But I am getting ahead of my story.

Thus the next best thing was to duplicate the absorption of solar energy in the sea for its evaporation. Studies showed that within one to two meter depth from the surface of ocean the solar energy is completely absorbed and this heated surface water, with the help of wind, evaporated to form clouds.

Thus I developed the strategy of using different colored dyes in a solar still to simulate this effect. The dyes absorbed the solar energy at the surface and hence increased the evaporation of water. The evaporated water was condensed under the glass cover and collected. This is the basis of simple solar still (pictured).

Solar still



This strategy formed the basis of my Ph.D. thesis entitled **"The effect of dyes on solar distillation."** and was published as a paper in Solar Energy Journal in 1979.[17] It is quoted extensively in solar distillation literature.

Though this gave me the Ph.D., the desire to learn how nature produces pure water for life led me to undertake studies on the mechanism of how mangroves and sea grasses grow in salt water and how some of the plants (called epiphytes) take water from air.

Studies of mangrove showed that their root systems develop a suction pressure of 30-60 atmospheres which is far greater than the thermodynamic limit of 25 atmospheres needed to desalinate sea water. The osmotic pump in the mangroves and sea grass is the evapotranspiration of water through their leaves. This transpiration of water from the leaves together with a molecular chain of water in the phloem (inside the bark in the outer layer of tree) is also the mechanism of transporting the water upto 100 meters in tall trees. Nature is very efficient and pumps water through tall trees without a pump with moving parts.

Further studies on how water is transported in trees showed that within very thin capillary tubes of phloem, water forms a molecular chain till the surface of leaves and each evaporating molecule from the leaf's surface pulls this chain up resulting in the flow of water through tall trees. In early 1970s there was no mechanism available to make such a structure. However with advancement of nanostructure science and technology, I feel that very thin and long glass capillaries filled with water can be fabricated and could be the basis of a **very effective pump and a solar desalination device**. Such a system will run only on solar thermal energy without any moving parts.


UF lab 1979

Based on the work in solar energy at UF, I also developed a simple method to heat water using tubes buried in the solar-heated sand (pictured). Thus a concrete tube half-buried in sand could heat the water very effectively since

sand acted as a giant solar collector. This method formed the basis of my paper published in 1980 on a large scale scheme for desalinating sea water[78] for potable purposes in Thar Desert in Rajasthan.

The scheme envisaged taking water from sea and passing it through sand buried concrete collectors. The heated water would go through the multistage flash evaporating system to produce fresh water. This is like a regular thermal desalination plant except that instead of using fossil fuels like oil and natural gas to run them this plant used solar energy. Again this paper is referred to by lots of researchers and even 35 years after its publication requests come from all over the world enquiring about the future of this concept. I feel that even today this concept is as valid or even more than it was in 1980.

After my return from US in 1981 I got deeply involved in developing rural household devices[79] and energy devices running on biomass.[63] Still I continued some work related to water.

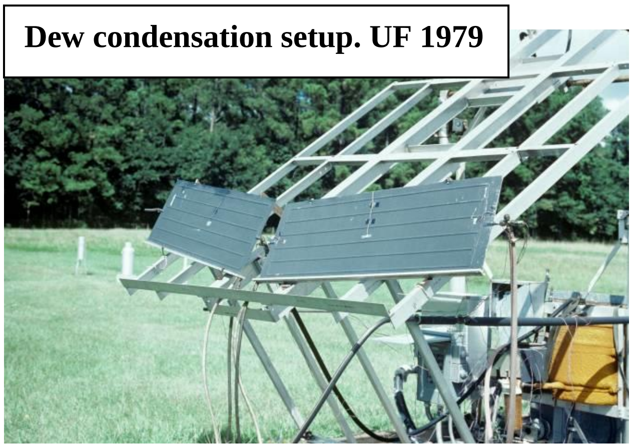
In late 1981 I had gone to Chilika lake in eastern state of Odisha. This lake is a brackish water lagoon with water inflow from Bay of Bengal. It has the largest migratory bird sanctuary in Indian sub-continent and has large area and mass of sea grasses. I collected samples of this grass and planted them in a specially made salt water tank at NARI. The idea was to see whether sea grass increases the water evaporation from such tanks. We found that because of the increase in surface area (area of leaves) the total evaporation from the tank containing sea grass was more than that from a tank without the grass. This showed that a solar still with sea grass in it could have higher distilled water productivity than the one without it. Unfortunately other activities at NARI took precedence and I left this work unfinished.

However even today I feel that such a unit with enhanced evaporation by sea grass and the use of grass biomass to produce energy will be an excellent system to produce both potable water and electricity near the sea shore.

Dew condensation

In Florida almost all the trees had Spanish moss hanging from their branches. The moss uses the tree branch for support but survives by sucking water from the air. Hence I became interested in the mechanism of how they suck the moisture from air (basically dew) and then a thought came that for large scale water supply in coastal areas of the world dew condensation maybe a better strategy than desalination since nature has already evaporated the water and hence the energy for evaporation can be saved in such a scheme. A chance news item in early 1979 on how dark beetles in Namibian desert condense dew at night on their outer shell and use that water to survive in harsh desert climate, made me think on how to duplicate natural design for dew condensation system.

Dew condensation setup. UF 1979



Since no reliable long term dew condensation data existed, I decided to generate it. Thus I rigged up a small dew condensation plant consisting of a solar collector sheet through which cold water circulated from a one ton refrigeration plant. This set-up condensed the dew at night on the aluminum panels and was collected in bottles. The plant was daily run for 4-5 months and to my mind was the first long- term dew collector anywhere. It gave us very good data on the various parameters affecting dew condensation such as affect of ambient temperature; humidity; wind speed, etc. Based upon this data I developed a scheme for large scale dew condensation as a means of fresh water supply and published it in Desalination Journal.[80]

The scheme envisaged bringing in deep sea water which is very cold (~5-6^{o} C) and passing it through the dew condensation collectors to condense dew. The plant was envisaged to be near the sea shore so that wind turbines could be used to pump water from the sea. The returning sea water from the dew collectors would also be used for marine culture and growing fish.

This 1981 paper [80] is still quoted and was probably the first paper on this subject of large scale dew condensation for fresh water production. The scheme has been copied and patented by researchers and developers all over the world. Today dew collection and harvesting (also called fog collection) for water production is a hot topic for R&D and a possible source of drinking water supply for urban areas.

In 1984 Municipal Commissioner of Mumbai invited me to advise him and his team on how to have an alternative water supply for Mumbai. Apparently the then Prime Minister Rajiv Gandhi's office had instructed him about the threat to Mumbai water supply from Pakistani agents and hence an alternative water supply was necessary. Somebody had also told the Commissioner about my work in dew condensation and solar distillation.

A special meeting was called in his office in Mumbai where I met him and about 10-15 senior staff members to discuss the issue.

I told them that the best way to solve Mumbai water supply problem was to have large-scale rainwater harvesting and making it mandatory for each housing society and to collect the condensate from the innumerable air conditioning units operating in Mumbai.

Most of his staff laughed at my suggestion and said that they had gathered there to discuss and hear from me some serious solutions! I then told them about the recent development of offshore ship-based desalination units which were being developed in Sweden. Immediately they all perked up since they saw a strong possibility of going to Europe on a fact-finding trip!

Today both rain water harvesting and dew harvesting through artificial refrigeration is being practiced world over and I feel that Mumbai would have benefited if they had started on these suggestions in the early 1980s.

Another interesting idea that I worked on in Phaltan in early 1980s was on cloud suction for producing water. Phaltan[81] is in rain shadow area of Sahyadri mountain range and its elevation is around 800 m above sea level. Because of the Western Ghat mountains the clouds from the Arabian sea, during the regular Indian monsoon, go over us and rain further east. We get our scanty rains (~ 500mm/yr) [82] mainly in September/October during the returning monsoon time.

This made me wonder whether we can somehow suck the clouds and condense them to produce water. This was basically an extension of my dew condensation work. So I developed a paper study for a scheme of large kites (in the shape of air foils) which would fly high in the sky (about 500 meters or so) and with wind power (wind is plentiful at those heights) the kite would suck the clouds and channel them through the tube which would also double up as "Kite string". On the ground a suitably designed refrigeration plant running on wind energy would condense these sucked clouds to produce pure water. One of the major design challenge was the stability of kite structure with cloud and wind loading.

Since then many schemes on the use of kites for wind power have been proposed and developed but none for cloud suction and condensation and I still feel that this scheme has merits. The advantage of this scheme over cloud seeding is that one can get water wherever it is needed. In cloud seeding one cannot predict where the rains will fall.

Water sterilization

As we were developing energy devices for rural households we became acutely aware of the lack of potable water in these households. Hence we thought of using solar energy to boil water. Thus we set up in 1984 a double-glazed solar collector which boiled the water in stagnation mode in batchwise process. However it did not work during the rainy season (June-September) because the solar radiation was drastically reduced and thus the water could not reach boiling temperatures. Hence an idea arose whether we can make water potable at sub-boiling temperatures – those that are easily reached in solar water heaters.

Recently in 2012 we have developed a system where the dirty water is passed through four layered cotton sari cloth and this filtered water is heated to 60ºC for 10-15 minutes. This treatment removes all the coliforms and makes the water potable.[83] This low temperature heating can be easily achieved even on cloudy days in an efficient tubular solar collectors. We have set up a small experimental unit and the microbiological data is being collected. The water from this unit seems to be potable since a Spanish intern has been drinking it for the last 4 months without any illness!

We also feel that the hot water from the solar sterilizer unit can be used to produce ice via the intermittent ammonia-water absorption unit. This ice can be supplied to each rural household and can be used in an extremely efficient insulated box to provide small refrigerator facilities. The challenge is to develop this ammonia-water system and the insulated box so as to make the whole system economically viable. We feel the solar sterilizer can provide both the potable water and refrigeration simultaneously.

Water for trees

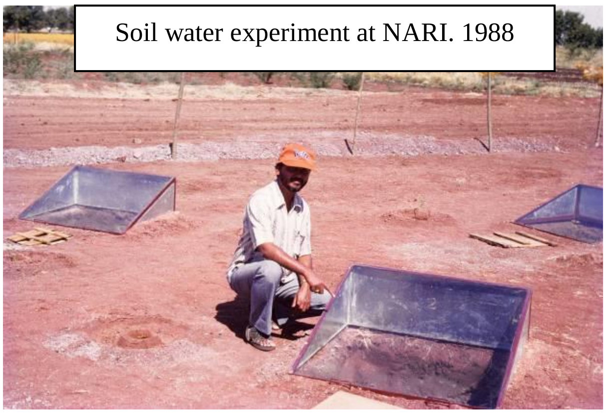
In early 1980s there was a major program of Government of India to increase forest cover in India. Hence funding and seeds were provided to various agencies to plant different types of fast growing trees. Phaltan area in early 1980s had very little greenery and tree cover and most of the trees planted died in early stages because of lack of water.

NARI experiment,1988

During my UF desalination work I had come across studies on producing water from soil for survival in desert. The technique involved digging a hole of about a foot in diameter and covering this hole with a plastic sheet. This plastic sheet was sealed from the sides and

weighed down by a small stone in the middle. A small cup was put in a hole below the weighed down plastic sheet (shown in photo). Moisture in the soil heated by solar energy evaporated and condensed on the underside of the plastic sheet and in one day a cup full of water was available for survival.

I thought of using this technique for producing water in semi-arid regions like Phaltan and then giving this water via drip irrigation to tree seedlings. So instead of plastic covered pit we made the top cover of glass just like that in regular solar water still and put it over the pit. The sides of the still were sealed by the soil.


Soil water experiment at NARI. 1988

We also developed the long-term data and studied the effect of various climatic parameters on soil water evaporation in Phaltan area and found that even in the driest season enough water (about 250-300 ml/day) could be collected from a 0.9 m X 0.9 m X 0.6 pit. This was sufficient for the seedlings to survive. We presented this work in the International Solar Energy Conference in 1991 in Denver[84], Colorado, USA and it was the first paper on such a concept of greening the desert! Since then this pioneering concept has spawned similar efforts all over the world.

These solar stills were reusable and long lasting and once the seedlings were established they could be put over the new pits. Besides being made of steel they can last for 10-15 years. The empty pits also act as rain water harvesters and helps in supplying it to the roots of the germinated trees.

In 1991 we gave the design of the solar soil water still to National Dairy Development Board (NDDB) in Anand for producing potable water in Kutch area. Dr. Varghese Kurien, the Chairman of NDDB had invited us to see the condition of salt makers in Kutch area and to suggest how they can produce potable water. The water table in these areas is quite high-almost at the surface and the water is brackish. So we thought our soil water still will be very useful for producing clean water. NDDB made

a good number of stills based on our design and we were informed that it supplied adequate potable water for the salt makers.

Solar detoxification of distillery waste

During our work in late 1980s on solar distillation of ethanol we found that for each liter of ethanol distilled about 15 liters of effluent is produced. This effluent which is black in color, very foul-smelling and has high biological and chemical oxygen demand (BOD and COD respectively) is discharged by most of the distilleries in local water bodies without any treatment. Since most of the distilleries are in rural areas and attached to sugar factories the effluent discharge pollutes the water and environment and is very harmful to the fields and animals.

Around four km away from my house in Phaltan is one such distillery. During our monsoon (September-October) the winds come from easterly direction over the distillery and this foul-smelling wind over the distillery effluent is really troublesome.

So we started thinking of detoxifying distillery effluent and thought of using solar energy to treat this waste and developed a scheme by which a suitable photocatalyst when mixed with diluted effluent and exposed to sun could reduce the color and the chemical oxygen demand.

After the lab experiments we set up a solar detoxification plant in 2002 to clean 100 liters of diluted effluent per day.[25] (Pictured left). The process made the water quite transparent, completely removed the smell and drastically reduced COD and BOD. We also tested this treated water on crops and found it to be beneficial to their growth.

We tried to sell this technology to lots of distilleries but they thought the price of photocatalyst to be high and also did not want to spend any money on treating the effluent since they could easily discharge it at night in the water bodies like canal,

rivers etc. With laxness and corruption in local pollution boards there is not too much incentive to go for such technologies.

Areas for future research and development (R&D)

R&D on water is a very vast subject. I am outlining the areas that we have touched in our work. Thus the following challenges exist:

(1) Study and duplicate the reverse osmosis (RO) mechanism of mangroves and sea grasses. This may help design better RO plants.

(2) Design and build an experimental cloud suction plant.

(3) Dew condensation for potable water production should be the strategy adopted for coastal areas. Condensation strategies as outlined in our paper[80] should be followed.

(4) Ship-based offshore dew condensation system should be studied. The deep cold sea water can be used for dew condensation and the fresh water produced can be stored in huge plastic floating bags. These can easily be towed to the shore for delivery of fresh water.

(5) Large scale deployment of soil water evaporation units can be useful in increasing green cover in arid regions and can be useful for horticulture plantations.

Team members:

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How to live sustainably

In the previous chapters we discussed various renewable energy projects done at NARI. I feel that those of us who work in the areas of renewable energy (RE) and sustainable development should also try to live sustainably ourselves. Besides if each one of us lives sustainably then it will help conserve the resources of this world. The consumptive life style of western societies is putting tremendous pressures on the world resources besides increasing earth warming and pollution. For example an average US citizen consumes 306 GJ/yr. of energy. If every citizen of this planet wants to have the wasteful and consumptive life style of an average American then we will need the resources of four earths to sustain us.

I would therefore like to share with you my experiences in living a sustainable but decent and emotionally satisfying life and would like to share some of the examples of sustainability that we follow in the Institute. My lifestyle has evolved slowly over time and required some effort. I had lived in US for many years in 1970s and had imbibed the consumptive lifestyle of US. Coming and living in rural India taught me many things among which was spirituality and frugality. Both these things go hand in hand and have helped me live in the way I describe below.

My experiments in sustainable living for the last 30 years are as follows:

1. I live in a house designed by me and constructed in 1984. It is built of stone with 18” thick walls which allow tremendous thermal lag-time, so heating and cooling due to ambient atmospheric temperature is delayed. It is passively cooled in the summer

by laying old jute gunny sacks on the roof and sprinkling water on them two times a day. These sacks are very cheap and cost Rs. 10/m^2. The evaporating water from the sacks cools the roof from where 80% of thermal load comes into the house. Thus when the outside temperatures are about 40-45^oC the house is cool in the afternoon with average temperatures of rooms ranging from 25-30^oC. This is mostly because of thick walls and cool roof. Besides we also close all the windows and draw the drapes over them so that hot air and radiation from outside does not come inside the house. The trees surrounding the house also help.

2. In the last 2-3 years we had scanty rains in Phaltan and so there is drought like conditions. To mitigate that and still keep the house cool without the use of water we have set up shade nets over the roof. These shade net cost Rs. 150/m^2 and together with gunny sacks provide adequate cooling for the roof. Such simple cooling system has also been put on all buildings in the Institute. The Institute buildings are also stone structures with 18" thick walls.

3. In a couple of years or so the gunny sacks are worn out because of the salts left behind by the evaporating water. These old gunny sacks are either used as mulch in the garden or burned in our hot water boiler, which supplies water for our daily bath. The water boiler is a grate-type multifuel boiler with about a 10 m long chimney attached to it. This chimney height gives an excellent draught and hence burns the wood and other material quite cleanly. In fact the water boiler is used for burning lots of different things as explained below. The ash from this boiler is used as a fertilizer in our garden either by putting it directly around the plants or in composting pit.

4. Phaltan is about 800 m above sea level and is 100 km south-east of Pune or 300 km south-east of Mumbai. Its climate is very mild. Still in some years during winters the minimum temperatures can reach 7-8 ^oC. Our house is not heated. We close the windows at night if needed and wear warm clothes and socks. It keeps us warm and comfortable.

5. All our kitchen waste is composted in a pit (dimensions of 1 m X 1 m X 1 m) and within 2-3 months it provides excellent fertilizer for the garden. Until couple of years ago we used to feed the kitchen waste to the rabbits (about 25-30 of them) who were in a cage in our garden and they provided manure for the garden much rapidly than the compost pit. However two years ago our garden was flooded with torrential rain and they all perished.

6. Similarly at NARI we compost all the agricultural residues from our farm in four huge pits. The residues after crop harvesting are brought to the pits, chopped into small pieces by chaff cutter and then put in them. Periodic water spray and additions of cow dung helps to produce good compost in 3-4 months. Use of such farm yard manure has drastically improved soils of NARI farm.

7. We never waste any food in the house. Whatever we take on the plate is eaten. The leftovers are either used next day or fed to our two dogs and few cats. There is no special food for the pets. They eat whatever we eat.

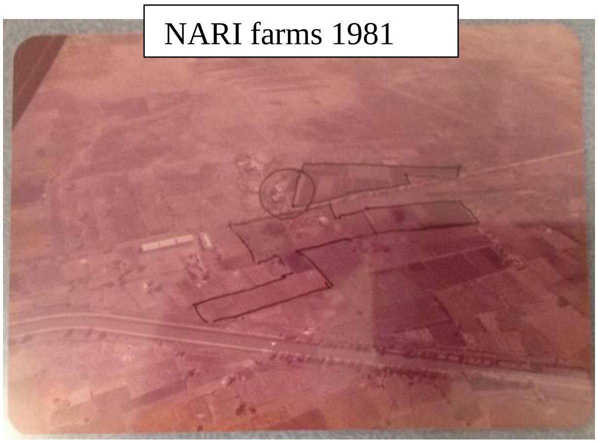
8. We have a 2-acre plot on which our house is located. It mostly contains trees planted by us. Their leaf litter rots in the soil during rainy season and provide nice mulch. The dead branches and trees provide us the wood for heating our bath water in the boiler. In fact we always have surplus of wood so that we sell it and make a tidy sum.

9. When we purchased this land in 1981 it was completely barren and the quality of land was so poor that there would be huge cracks – big enough for whole sheep to disappear in them. We planted about 30 different types of trees. With time the trees have grown so that the garden is presently like a tropical forest.

Last count showed that there are about 40 different types of birds which either live in our garden or take refuge during migratory phase. The leaf litter from the trees and the compost fertilizer has improved the soil quality and it has therefore become springy and quite fertile.

10. Similarly when the NARI farms were purchased in late 1970s they were mostly barren. With the use of irrigation water from the Nira Right Bank canal and organic fertilizer from the compost pits the lands have become very fertile.

NARI farms 1981



11. Most of our groceries and vegetables are grown within 10-15 km of our home. The eggs are mostly from free ranging chickens, milk from cows across the road and vegetables and groceries from the local market. Most of these things are grown in Phaltan area. We use safflower seed produced on our Institute farm for crushing in the local mill for oil. Thus the oil is fresh and without any chemicals. We also consume some fruits grown in our own garden.

12. Until very recently I drove my 31 year-old Maruti 800cc car which transported me from point A to B comfortably. After being driven 150, 000 kilometers it has been retired since it cannot be insured and neither can I get spare parts for its repair. So now I drive Maruti Alto an efficient small car which gives me between 18-20 km/liter and is small enough to go in the smallest of lanes and by- lanes of Phaltan town. For long distance driving to Pune or Mumbai (300 km from Phaltan) I use Maruti Esteem which also gives an average of 18-20 km/liter.

13. We have few clothes and they are worn until they get torn. They are then used in the house as dusters and wipers and after becoming tatters are used in the water boiler to heat the water.

14. Mostly I wear khadi or cotton spun in cottage industries. Thus I buy the cloth for my bush shirts and they are stitched by my tailor in Phaltan. This makes these shirts much cheaper than the ones purchased in the market. Khadi is a very comfortable material to wear and also makes excellent dusters and wipers after the shirts get torn.

15. Similarly all the papers in the office are used for writing on both sides and the used ones are brought to our house to again heat our bath water. Thus we try to recycle most of the things.

16. We use electricity sparingly – which till recently was facilitated by the Government of Maharashtra since we used to have 3-4 hours of power cut every day! We have battery-powered inverters both in the offices and at home which supply enough juice during power cuts for lights, fans and computers only. Therefore, no TV or refrigerators run on them. During electricity cuts we walk, talk or read. This provides a good quality time to catch up on reading and discussions. Sometimes I think this is for the best as 24-hour electricity with TV and other electronic media running continuously causes distraction.

17. We do not travel very much but communicate more by phones and internet and believe that this is much more energy-efficient way of keeping in touch. With availability of broad-band internet connection both at home and in the office, it is an excellent communication and information medium.

18. We bring most of our groceries and vegetables in cotton carry bags and hence have little garbage of plastic. Nevertheless we cannot get away from plastic as most things come already packed in it and this is the biggest nuisance we have. We have no way to recycle it. Presently we take the plastic bags and bottles to the local garbage dump from where they ultimately go to the recycling center. Still I feel we use much less plastic than most people. The technology for recycling of plastics in rural areas is not available and is very much needed.

19. We are teetotalers and drink only water, which is boiled. Thus the plastic bottles and cans of soft drinks do not litter our garden. Drinking only water is not only healthier but also helps the environment by not producing plastic bottle litter.

20. In the Institute the water is purified by solar energy through our innovative **solar water purification system**. It produces about 45 liters of water every day and is sufficient for the staff.

21. We buy only those things which are needed and since we live simply we do not need to buy too many things. We still use one of our 25-30 year old refrigerators and try to get most of our gadgets repaired rather than throwing them away when they stop working. This reduces the garbage production and at the same time is easy on the pocket book. However India is rapidly developing into a throwaway society and hence it is becoming increasingly difficult to get the old gadgets repaired.

22. The main external inputs we use are electricity for lighting and gadgets, petrol for transport, and liquid petroleum gas (LPG) for cooking. Our per capita energy consumption (from last 2-3 years data) is 14.5 GJ/yr. for electricity (both in offices and home), 10.8 GJ/yr. in transport (mostly for petrol for 2 cars) and 2.1 GJ/yr. in cooking gas. Thus we personally consume ~ 27.4 GJ/person/year of energy. To this should be added the energy in India's infrastructure which comes to about 10 GJ/person/year. Thus our total commercial energy consumption is ~37.4 GJ/person/yr. Contrast this with about 306 GJ/person/year that an average U.S. citizen uses. Thus in 1/8th the energy that is used by an average America citizen we can live quite decently in a modern industrial society.

23. Our low electricity consumption results since we use only fans and LED/CFL lamps and evaporative or passive roof cooling system. Even in our offices we use evaporative roof cooling. We do have an air conditioner (AC) in our bedroom and in my office but it is hardly used because of passive evaporative roof cooling system. Last 8-10 years data show that we have used AC for 15-20

days a year during the humid weather. The low energy usage in transport is because on an average we travel between 15-17 thousand km/yr.

24. If air travel is added to the above energy then the consumption increases drastically. With the energy norm of 1.3 MJ/passenger-km for air travel a trip to US from Mumbai consumes 28.3 GJ/person of energy while each domestic air travel consumes ~ 3GJ/person. Thus last year we made four domestic and one foreign trip and hence the total energy used was 86 GJ/person. This is still less than 1/3rd the energy consumed by a US citizen. Though our air travel is quite limited but still it is the biggest user of energy in our case. Interestingly if every person has the energy consumption pattern like ours then one earth is sufficient to provide all the energy needed by mankind.

25. Similarly our average water consumption is 180 liters per person/day for household purposes. This is almost one-fourth that used by a U.S. citizen. In late 1980s we did an experiment of rain water harvesting. We set up a small hut like structure in the Institute and collected the rain water from its roof in a cement tank. Even in Phaltan with 500 mm rainfall/year we were able to show that the area of small hut roof is sufficient to collect all the water needed for yearly drinking requirement for a family of 4-5. We abandoned this experiment at that time (1986) because there were no economical methods available to clean the stored rain water. We now feel that our solar water purifier in combination with roof top rain harvesting can be an economically viable answer for drinking water requirements for families in rural areas.

26. Our new building Bajaj Center at NARI has very innovative sustainability features. Again the passive roof cooling concept has been incorporated. Besides it has rain water harvesting features, solar powered water pumping, solar water heating for residential facility and all the water used in the facility is fed into our farms. The kitchen waste is put in the compost pits. The details of these features are given in the website of Bajaj Center.

With these examples I feel a satisfying and decent life style can be maintained in much less energy and water usage as compared to that in western societies and do

hope may inspire the readers to do their own energy calculations for sustainable living.

We can make the life style even more sustainable by producing electricity, liquid and gaseous fuels from agricultural residues so that our household gadgets and mobility machines can run on locally produced fuel. Similarly electricity production from solar energy can further help in this process. However both these things will require a community effort, reduction in costs of equipment, together with certain policy changes by the Government of India. Nevertheless if all of us become internally secure through spirituality then it can help us reduce our greed for materials and resources and help us in living sustainably. And with proper planning and enlightened policy of the Government, Indians can enjoy a very high quality of life without becoming over consumptive.

Truthfulness of data

(this chapter was added in February 2019)

One of the biggest hurdles that we faced in doing good R&D in a rural set up was getting good truthful data.

In a society which gives premium to passing exams and where the whole basis of education is fixated on getting good grades by any means, it becomes very difficult to instill in young students the ethics of work. And it showed in the people that we hired.

We were probably the first Institute in India to do field testing of agrochemicals in early 1970s. Almost all the major companies in India who produced agrochemicals got their products tested in our Institute. Our reports were accepted by the Central Insecticides Board in New Delhi and this activity gave us a good source of income.

We even hired a Ph.D. in entomology to do the testing full time. Initially he did good work and very soon we found that many more companies started coming and the activity really picked up and thrived. In fact we started getting repeat orders from some of the largest and most reputable agrochemical companies of India. We were very happy with this state of affairs. Since the Ph.D. scientist in charge of testing was given totally free hand we never bothered to check his experiments or the results.

One day just on a whim our President looked at the report carefully and then went to the field to check on the experiment. She found out that there was no experiment in the field ! The scientist was cooking up the data in his office.

This seemed to be the joint project of the scientist and the company representative! The company got the report they wanted, the scientist complied with their instructions in preparing it and he may even have been getting a cut directly from the companies. He was immediately fired and our president took up the charge of conducting the experiments herself.

When she had the experiments done under her direct supervision she found that often times there was hardly any difference between the control and the treatment with agrochemicals. The agrochemical companies told her that she was incompetent and that the earlier scientist was doing a good job.

Finally one of the senior managers of a very famous company had the gall of telling her that scientists from the agricultural universities gave him the reports with the results that he wanted and everybody was happy ! In fact he brought some data and told her he wanted data like that for the trial underway at our Institute ! That was what was happening with our scientist. He must have thought what was the need to conduct a field trial when the required data was being supplied by the company and so he was cooking up the report; the Institute was getting good money; the companies were getting their registration. So this was a win-win situation !

The managers from these big companies were Ph.D.s from good universities and yet they had no qualms in being totally dishonest and fraudulent. When we complained to the top management of the company they stopped our business stating that we were incompetent and they also sent a message to the Central Insecticides Board that our results were useless.

We lost a good business but felt that this was the only honorable thing to do.

This type of dishonest behavior is quite rampant in most organizations in India and thus it is very difficult to trust the data produced in India. One has to be constantly on guard and supervise and force the scientists to produce good reliable data.

Very often I have stressed to our scientists that no data is far better than cooked up dishonest data. With no data at least one can conjecture but with cooked up data totally wrong conclusions may be drawn. It is quite possible that mistakes may happen because of sloppy data taking, but cooking up the data to conform to expected results is very dangerous.

Similarly we found that in agricultural research quite a number of times the data was being fudged and cooked. There are innumerable examples of these.

The biggest tragedy is that one has to constantly supervise and look over the shoulders of the scientists to check each and everything–something which is very tedious, time consuming and irritating. The scientists have to be trusted. Good data taking requires work and most of the times I have found the scientists are quite lazy in doing that. And with ethics of work missing they have no qualms in making up the data.

I also sometimes feel that probably it is not the fault of the people we hired. It is the fault of our education system which lays great stress on only passing exams and not doing any field or hands-on work which makes the scientists treat everything without much seriousness.

Thus good, reliable data taking is a part of ethics of work and if our children and youth in school and colleges are taught ethical behavior then we will not have the problems outlined in this chapter.

This chapter was added in February 2019.

Roadmap for Rural India

Our work on hardware development, discussed in previous chapters, has given us good insight into the whole subject of rural development. Based upon it I would like to propose a possible roadmap for rural India. Since thoughts and challenges on renewable energy have already been covered in the previous chapters, I would like to discuss in this chapter issues related to rural livelihoods and the philosophy of rural development.

I must also state that this is being proposed in all humility since thousands of people throughout independent India's history have thought deeply about it and hence it would be arrogant on my part to show this as a new path. The roadmap has come from our limited experience and we hope it can form a part of the general development model for the future.

Basically the roadmap has the following components:

(1) To improve the lives of rural poor by developing a mechanism for availability of modern devices for rural households at reasonable prices.

(2) Creating rural livelihoods.

(3) Getting smart and intelligent youngsters and the best brains in the country to engage in rural development.

All three components have to work in tandem to produce rural prosperity and to stop the migration of rural population to urban areas.

The problems of India are huge. When Jawaharlal Nehru, our first Prime Minister, was once asked how many problems he needed to solve to make India a great country, he remarked, "300 million." (That was the population of India at the time.) His statement is still valid but I feel that rather than looking at the whole range of problems, if we can provide solutions to the above three then the solutions to the rest will follow.

Improving the lives of rural poor – one hut at a time

Long ago (mid 1990s) I visited the hut (tin shed) of a farm laborer called Sidhram in the nearby village of Vinchurni. The evidence of poverty I saw in his hut shattered me and propelled me to look at solutions to make the lives of the rural poor better. He had a broken kerosene hurricane lantern for light; the broken glass chimney had become black with soot. He cooked food in a few beat-up aluminum utensils and mostly survived on *bhakari* (sorghum and bajra bread) and *chutney* (made up of green peppers and some spices). He cooked his meal on a three-stone wood stove and ground the chutney on a flat stone grinder. He had a few clothes which he washed every day, and a thin mattress with a worn-out sheet that also doubled up as a pillow. These were his total possessions. Anytime I think of a rural household, the image of Sidhram's hut and its belongings comes in front of my eyes. His case may be one of extreme poverty but a majority of the rural population in India lives in similar conditions.

In fact it should be a matter of shame for all of us that even 67 years after independence, 60% of our rural population (100 million households) lives in conditions of poverty similar to Sidhram's. They lack the basic amenities of life that we take for granted. For example they live in one-room huts with nearly non-existent electricity; cook on primitive biomass cookstoves which produce tremendous indoor pollution; lack potable water and toilet facilities. Somehow modern technology has not touched their lives. According to the latest World Bank report, 33% of the world's poorest live in India! [85]

Yet, there is another India which has an ambitious space program, is a world powerhouse in the Information Technology (IT) sector, and aspires to have an economy that is among the top five of the world. I feel that unless and until this 60% rural population is brought into mainstream development and their lives improved, India cannot become a great nation and join the league of major economic powers.

There are lots of areas to be improved before a real dent in rural poverty is made and I will try to outline in this chapter how this can possibly be achieved. I will however focus mostly on energy since we believe that energy is the basis of life and from it flow all other issues like those of environment, commerce, society, etc.

For starters it is necessary to decide what services and energies are needed for rural households. From our work with rural poor we believe that they should have a house with two rooms, a kitchen and a toilet. For providing energy to this household our calculations show that they should have 1220 kWhr/yr of electricity and 260 kg/yr of liquid petroleum gas (LPG) or equivalent biogas.

This amount of electricity can provide energy for two fans, four LED lights (providing 500 lumens each); a small refrigerator (20 liters capacity); charging phones; and transport. We believe that electric motorcycles[74] are increasingly becoming more efficient world over, and powerful enough to form the backbone of rural transport. Similarly motorbikes running on air[75] are also becoming available. These motorcycles are far more efficient and environment-friendly than petrol-driven ones. Presently they are quite costly and so the main challenge (Chapter 4) is to bring down their cost and run them on electricity from locally produced resources.

For cooking and heating, the best and most user-friendly fuel is liquid petroleum gas (LPG) or an equivalent amount of biogas (mostly methane). The amount of 260 kg/year per household will take care of all the cooking and hot water requirements for a family of five. LPG or liquid fuel systems with excellent combustion, like kerosene lanstoves,[35] can provide a user- and environment-friendly source of energy for cooking.

With the above facilities and energy consumption the quality of life of the rural poor can be drastically improved and they can join the middle class. To provide the above energy for 100 million poor rural households we need to add about 14,000 MW electricity capacity, and double the LPG production. Both are doable goals and the challenge is how to produce this energy from locally available renewable fuels like solar, wind and biomass.

Incidentally, the Government of India's Planning Commission (PC), in its energy policy document of 2006,[86] has only made provision for 365 kWhr/yr of electricity and 72 kg of LPG per rural household. This is only about 1/3rd of the energy as

proposed by us. I feel this meager amount of energy, proposed by PC, will continue to keep the rural poor in the poverty regime.

I have always believed that we should approach the issue of poverty by being personally engaged in it. Thus each of us should ask ourselves whether we would be able to live in those huts with the available amenities. This is the approach we have followed in deciding the energy and amenities to be given to the rural poor. I feel if each of us uses this criterion of whether we can live (simply and not ostentatiously) with the facilities and amenities that we propose for the rural poor then a whole paradigm shift can take place in removing rural poverty. This is the method we employ in training our interns and engineers. We expose them to the poverty in rural huts and then ask them to think about devices that they would like to have to live simply in these huts. This approach offers a great challenge for designing better devices for rural households.

But a bigger challenge is how to provide drudgery-reducing devices to rural households at affordable prices. Most of the devices and services are produced and sold by the corporate sector. During the socialistic past of our country the Government of India (GOI) and public sector were involved in providing some of them but that era is gone and now these are provided by the private sector.

So, how do we get the private sector involved in improving the lives of the rural poor? Presently their strategy is based on one principle and that is to produce goods for urban areas and let the market forces eventually diffuse them to rural areas. This strategy has worked so far partially but has consequences in terms of cost and energy.

For example, majority of the devices for urban households run on electricity (mostly unavailable in rural areas) with the result that drudgery reducing devices are not available in these areas. The strategy therefore should be to develop household goods which run without electricity or use very little of it. This can have major implications on the design and development of new products.

These goods are shipped thousands of kilometers away from the place of their manufacture to where they will be used, consuming huge amounts of energy in transport. Modern technologies like 3D printing (or desktop manufacturing)[87] have an ability to transform the rural landscape by providing household devices at minimal energy and whenever and wherever they are needed. It is quite possible that this will give rise to small scale manufacturing units in rural areas producing goods under license from large companies. As the technologies evolve, these 3D machines will become quite cheap. I believe providing 3D manufacturing in rural India will be a great challenge, and prove to be transformative.

At present most of the 3D printing uses plastic as raw material. This raw material can be obtained from the plastic waste littering rural areas. Presently it is not properly recycled with the result that the countryside is littered with plastic bottles, bags, wrappings, etc. This is one of the biggest banes of rural India. 3D printing may provide a mechanism for recycling this plastic waste and thus enough incentive to collect it.

Excellent and energy-efficient devices world over are an outcome of good R&D. Most of the corporate sector in India has no mechanism of doing R&D, especially for rural areas. Somehow technology risk-taking is not in the DNA of the Indian corporate sector. Thus, they take only fully developed and proven technologies to manufacture and sell. Part of the reason is that most companies in India are not equipped to do R&D; another reason is that the captains of industry just do not believe in R&D. That is the reason why we buy technologies from abroad most of the time and now are even buying products from China! By sensitizing the corporate world regarding the need for R&D and opportunities for it in rural India, this lacuna could be addressed. Towards that goal we have set up a center of sustainable development at NARI[88] where we hope to forge NGO-corporate partnership.

The corporate sector has not come from another planet. It consists of people from regular walks of life including some who have even come from rural areas. But somehow the razzmatazz of urban life, corporate culture and general milieu seduces them and they forget about the problems of 60% of our rural population. How to

bring these problems in their vision field and to facilitate R&D on them is the biggest challenge.

One way to do this is constant education of the managers and captains of industry regarding these issues. This should also include the awareness that India Inc. survives only because these rural poor help in providing food for them. As a nation we cannot survive by eating software or nuts and bolts!

Another way is for the GOI to take a lead in forcing industries to do R&D for rural areas. There are estimates that the GOI already gives sops, tax write-offs, etc. to the corporate sector to the tune of Rs. 5320 billion/yr (Rs. 5.32 lakh crore/yr).[89] This is in addition to the billions of rupees that the Indian banks write off as bad loans. Incidentally this much money is five times more than the subsidy given to the poor via the Public Distribution Services (PDS) scheme! I think a duly elected strong government can use its power to bring an R&D culture for rural innovations to the corporate world.

The much-touted PPP (public-private partnership) should be implemented for a national mission for 'Improving rural lives – one hut at a time'. If we can have a successful space program run in mission mode, we can make a success of this vital mission too. But there is a need for political will to take the lead.

For starters GOI's innumerable R&D establishment can be given a mission and mandate to develop devices for rural households. GOI spends nearly Rs. 30,000 crores/yr in its R&D labs and employs about 90,000 full time R&D personnel in them.[90] These labs are equipped with excellent R&D facilities and modern equipment. Even with such a huge expenditure, unfortunately there is hardly any worthwhile output in any field let alone for rural areas. One of the main reasons is lack of vision and direction. If this huge R&D manpower in these establishments can be made to solve the problems of rural areas in mission mode then it can result in transforming India.

Additionally government can herd the private sector towards developing R&D for goods and services for rural areas and make it a part of Corporate Social

Responsibility (CSR)[91] activities of industries. After all, improving the quality of life of the rural poor is the most appropriate CSR activity! The GOI can also increase the limit of CSR spending by corporates from 2.5% to a higher percentage for rural R&D. This will hopefully bring an R&D culture into the corporate world.

This is the age of innovation. Every product that we use in our daily lives is the result of excellent R&D by both private companies and Government labs and universities, mostly in western countries. Why we cannot learn from them and implement this strategy of increasing R&D infrastructure in our country is something that is beyond my comprehension. Innovation allows price reduction of goods and allows them to be manufactured more efficiently with less energy. Our industries know this cardinal principle and yet they do not practice it. In fact Indian companies are some of the lowest spenders on R&D in the world.

Business-wise it makes sense for India's private sector to develop and manufacture rural household devices with inputs from excellent R&D. There are close to 3 billion poor people world-wide who can benefit tremendously by the inventions of Indian companies. Today these people get most of their goods from China. In order to become major international players Indian companies need to penetrate this market with outstanding products; spending money on research will benefit them in the long run.

Rural livelihoods

In order for the rural poor to afford household goods it is necessary that their purchasing power is increased. That can happen by improving their livelihood choices.

Around 80% of India's rural population is involved in the farming sector. A majority of the landless work as farm laborers and are the rural poor. Their lives can be enhanced by increasing their wages through improved farming. Agriculture in India today is in the Stone Age. There is a need to modernize it.

Traditionally, agriculture has been considered mainly as a provider of food. However, it can also provide energy and developing this dual-purpose function to

provide both food and energy security[92] will create a major transformation in India in terms of increased remuneration for farmers, and energy production.

India produces 600-800 million tons/year of agricultural residue. Residue is what is left of the plant after the food is harvested from it. A major portion of this dry residue is burnt in the fields as waste disposal since the farmers want their fields ready for the next crop. Not only does this create tremendous air pollution but it is a waste of an important energy source. There are also speculations that this residue burning is creating a brown haze over the subcontinent and could be the source of climate change in this area. Our work on sugarcane leaves gasification[24] was initiated to solve this problem.

There are many ways by which these residues can be utilized for producing energy and enriching the soil. If this entire agricultural residue is gasified or burnt in the biomass-based power plants, it has the potential of producing close to 80,000 MW of electricity, or nearly 50% of India's total installed capacity. Biomass power plant technology is very well developed and there are close to 140 plants in India with installed capacity of about 1000 MW. The power production from such plants is clean and renewable.

Alternatively, this residue can theoretically produce about 150 billion liters/year of ethanol via lignocellulosic conversion and can take care of about 50% of India's total oil demand. Similarly, if we go via the pyrolysis oil[93] route, we can meet around 80% of India's diesel demand. Pyrolysis oil is produced by rapid heating of dry biomass to 500-600°C and quenching the smoke rapidly to produce oil. With the help of suitable catalysts this oil can be converted into automobile fuel.

The residue can also be converted into biogas, which can provide energy for cooking and decentralized electricity production; the slurry from the gas digester can be an efficient fertilizer. Which route the residue will take will be dictated by the market forces, i.e., how much money a farmer gets for them?

The use of residue for energy production can substantially ease India's present energy crisis and can be a Rs. 2 lakh crore/year industry. At the same time the use of biomass for energy production can also produce nearly 50 million jobs in rural areas.[94] Thus, farming for energy can create huge wealth and infrastructure development in rural areas and lead to a prosperous India.

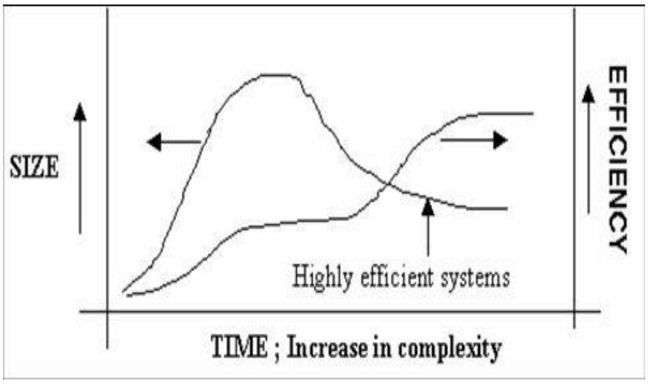
For this to happen two things are necessary. Firstly, farmers need to be paid for the agricultural residue, and secondly, agriculture needs to be modernized through inputs of high technology.

It is a peculiar aspect of farming that only 25-40% of its produce fetches money and the remaining 60-75% is agricultural residue of little value and has to be discarded. No industry can run on such norms where 3/4th of its produce is not sold and is in fact discarded. Yet, for farming we accept these norms.

When agricultural residue is capable of producing very high quality energy like electricity and liquid fuels, it should be given very good price. Our estimates show that with proper pricing of this residue, a farmer can easily earn about Rs. 5,000 to Rs. 7,000/acre/season by selling it for energy production.

Any marginal farmer can produce agricultural residue even if the main crop fails. The income from this residue can give him benefits even in the case of distress sale of his crop, and this is the best hedge against farmers' suicides. I also feel that unless and until the farmer gets remuneration from his entire produce, farming will never become economically viable. This is an aspect of farming which should be understood by policy planners.

The second aspect of farming is the need for very high science and technology inputs. High technology allows the efficient conversion of dilute locally available energy resources like biomass, solar, wind, etc. (which rural areas have in plenty) into useful end-products and services. In this process we need to follow nature and so biomimicry should be the mantra of technology development.



Natural systems have evolved into very efficient materials and energy converters. In this process, the size of the system reduces and its efficiency and complexity increases (as shown in the graph). Besides, they also become robust.

Some of our designs and technologies are following this strategy. For example, computer chips, cell phones, power plants, etc. are all becoming very efficient, small in size, complex and robust. Technology developers should follow this strategy in developing rural technologies. In fact, much more sophisticated thought and 'high' technology is required for solving rural problems since the materials and energy resources in rural areas are limited and often only available in 'dilute forms'. In most rural areas, efficient after-sales service is not available, making it even more essential to develop robust and foolproof technologies for these areas. Classical examples of such 'technologies' are all living systems. They are complex, robust, sophisticated and highly efficient.

We were the first to propose this approach of high technology for rural areas[95] more than 20 years and now it is in vogue. This approach is superior to the normal approach of tinkering or '*jugaad*'[96] which has been the mainstay of most rural development work. We believe that all technological progress and evolution, whether for urban or rural areas, should follow the route of good products. This route is based on excellent R&D; its manufacturing, sales, and excellent after-sales service. *Jugaad* and tinkering do not follow this cycle and hence are too person-dependent and ad-hoc. Consequently this does not allow quality goods to be produced and made available on a large scale.

Presently most of the agriculture in India functions as if in the Stone Age. There is very little mechanization and ancient agronomic practices continue to be used, with the result that our farm productivity is one of the lowest in the world. The problem has also been compounded by the fact that because of land reforms and practice of equal division of land among one's children, land holdings have reduced thereby

restricting the use of existing big and heavy farm machines. Presently 80% of farms in India are less than 2 hectares (ha) in size. In fact this small farm size could be a boon in disguise since it can allow the use of precision agriculture[97] (PA) which allows the use of inputs to the crop at proper times and precisely; in the process reducing inputs and increasing productivity. PA is becoming quite popular in western countries.

Nevertheless very extensive R&D is required for developing efficient machinery [97] for small farms. This requires an infusion of very bright young scientists and engineers into the farming sector. Presently all the bright students opt for engineering, medicine, MBA, etc. and agricultural sciences and engineering have limited appeal. There is a need to make agriculture attractive for bright students. One possible way is to make them interested in precision farming which is mostly robot and drone-driven.[97] This will need very creative programs in engineering and other agricultural sciences and may help create a huge educational infrastructure.

Another major problem of farming today is that since it is non-remunerative, farmers' children do not want to get into it. There is a general refrain that farming is not a dignified profession anymore and that the sons of farmers are not considered to be a 'marriageable commodity'! Besides being uneconomical, farming is also hard work. By developing high technology farming equipment like small tractor-mounted combines, harvesters, bailing machines, etc. for small farms it is quite possible that farming can be made less labor-intensive and more attractive to the younger generation. Advertisement agencies need to make a very concentrated effort to make agriculture seem glamorous. Once farming becomes remunerative through the production of both food and energy, it will also become glamorous!

'Glamorous farming' not only will stop the migration of the rural population to urban areas, it may even start the reverse flow from urban to rural areas. This is very different from the present thinking among the planners and policy makers in India and other developing countries that the march to urbanization is unstoppable and hence all planning should focus on improving megacities.

I think this is based on faulty premises of centralized planning. The natural evolutionary process is for decentralization. The megacity model was based on high intensity fossil fuels. Low intensity renewable energy fuels like solar, wind, and biomass will produce decentralized societies. I feel that is the future not only for India but for the rest of the world, and I believe that with high tech precision farming even western societies will become more agrarian.

Societies are like dissipative structures of Prigogine.[98] These dissipative structures (like convection currents of water heated from below) are dependent on the quality and quantity of energy supplied to the system. Thus, dilute low intensity energy like renewables will produce a decentralized society. India is already a decentralized rural society and hence it will be in our interest both energy-wise and resource-wise to enhance the decentralized structure by using renewable energies through high technology devices. Mahatma Gandhi intuitively believed in a decentralized rural society,[99] and high technology farming can bring that vision to reality.

The modernization of agriculture will have a tremendous impact on the infrastructure of the country. For example, the farm-to-table food chain requires a whole slew of infrastructure development. Thus roads, electricity, mobility, food processing, development of cold chain, etc. have to be expanded and modernized. This is how the agriculture and food industry has progressed in western countries, though the process is mostly very energy-intensive and wasteful. For example, in the U.S. oranges harvested in Florida are processed in California and then shipped back to Florida in cans!

For India it is necessary that the farm-to-table distance is reduced. This can happen by developing machines and systems for storage and processing. Today the farmers need to sell their raw produce immediately for fear of spoilage. Thus they are at the mercy of middlemen who make maximum money in the food chain. With storage facilities and food processing farmers can sell their products whenever and wherever they want to the highest bidder. This will require decentralized energy production, local food processing, and setting up of eateries and restaurants in local areas[41] on a large scale.

Water Issues

However, for farming to increase so that it can bear the increasing load of food and energy production, adequate water supply has to be ensured. To my mind, supply of adequate water to rural areas and poor regions of the world is a much bigger challenge than even energy availability, and an area where engineers and technologists can play an important role. There is a big scope for infrastructure development in water issues.

With the coming of the Green Revolution to India, there has been an extensive use of water, resulting in shortages in some parts of the country. India has the highest rate of ground water usage of any country in the world. Not only is there a water shortage, but lack of clean potable water results in millions of deaths every year due to diarrhea and other diseases. This is despite the fact that there is enough rainfall. Every year India receives ~ 4000 billion cubic meters of rainfall, whereas the present yearly water consumption is only 650 billion cubic meters, or 16% of the total rainfall. Theoretically we have enough clean water, but the rainfall is not evenly distributed over India and it comes in short spells, thereby pointing to the need for rainwater harvesting and storage programs.

The issue of rainwater harvesting and its supply to the communities in rural areas raises a question of who will own the water bodies. This is a touchy issue that quite a few developing countries are grappling with. I feel there is a need for the local governments to develop policies so that rural water utilities can be set up to harvest the rainwater, store and clean it, and then supply this water to a village throughout the year. These water utilities may also be able to buy water from the government through the existing canal system thus ensuring year round water availability even when the rains fail.

Presently, most of the water utilities in India are owned by the government and this leads to corruption in supply of water and its very inefficient usage. In 2003, the Government of India passed a revolutionary electricity act[100] allowing for the first time the private players to produce, sell and distribute electricity anywhere in the country. This act has allowed power producers to break free from the clutches of

inefficient and corrupt government power utilities. A similar water act will help in the efficient supply of water to rural areas.

However, for this program to move forward there is a need for large scale deployment of qualified engineers and technicians who are trained in rainwater harvesting and other water-related technologies. Rainwater harvesting technology and management should be a compulsory minor in all engineering and agricultural universities and colleges. This will help not only in agriculture but also in watershed development.

I strongly feel that when the farmers are neglected the long term sustainability of the country is threatened. When farms produce both food and fuel then their utility becomes manifold. In India around 55% of the population depends on farming; with energy from agriculture as a major focus, India has the potential of becoming a high-tech and wealthy farming community. This will help improve the rural environment and create a better India.

Best brains for rural development

The two components of the roadmap discussed above can only be taken forward by truly dedicated people. Getting the best and the brightest people for rural development is the biggest challenge.

One of India's biggest assets is our people. India is a young country with 54% of the population below 25 years of age. The energies of this youthful population, if directed for rural improvement, can bring about wonders for India. However, to train and guide them to be useful to society is a big challenge.

With the focus in our society on making money by any means, which ultimately leads to corruption, the training of youngsters has suffered tremendously. This reflects in their education which hardly teaches them any skills but only how to pass exams;[5] the focus is on rote learning and not on working with the hands. Basically we are creating a nation of clerks – upper division and lower division! It is a well-known fact that most of our science and technology graduates are unemployable. It is not the fault of these students but a corrupt and broken education system which most of the

time fleeces these students without imparting any meaningful education. We as a nation are playing with fire since we are ruining the lives of our young generation.

In my innumerable interactions with young students all over the country I have always got the impression that they want to learn and do something meaningful in their lives. Yet they are neither shown the opportunity nor the path because of the paucity of good and motivated teachers.[6] I am sure if given a chance and provided motivation our science and engineering students can do wonderful work and help the country.

A good way for students to be involved in rural R&D is for them to spend one or two years doing work or internship in rural science and technology (S&T) NGOs like ours.[101] At any opportunity I get, I try to inspire them[7] and make them enthusiastic about spending a year or two as interns in rural NGOs. This is one of the ways to get them sensitized to rural areas. If they can understand the problems of the rural poor while doing rural internships, they will be able to attack and solve them later on when they have resources and materials as corporate managers and honchos.

This is not an easy task since pressure from their peers and parents forces them to think about internship only in terms of money and how much they will be losing. Often, after my talks in various institutes the students have approached me to do internships in our Institute and then under pressure from their parents they have balked. How do we change this outlook and make these students bold enough to take such a step is a great challenge. I even tell them the story of how I came back from the U.S. and went directly to rural India,[1] but they think that I was mad and they would not like to join the club!

I think their reluctance to take this step comes from the fear of losing out. The money angle has been so hammered into them by their parents, peers and society that they do not want to learn and increase their skills or contribute to society.

Despite their fear of losing out, I feel that the younger generation is smart and if properly guided can be made to contribute to uplifting the rural population. This can

be done by continuously reminding them in the classroom about rural problems and about the joys of giving back to the society.[15] The focus should be on modifying the educational curriculum to reflect this strategy. The mass media can focus on rural success stories that will inspire youngsters to spend a year or two in these areas. For this to happen, the number of rural S&T NGOs where youngsters can do internships needs to be increased.

Presently, students have genuine fears that by working for a couple of years on rural problems they will become unemployable. It is an egg and chicken story. The corporates do not want to do any R&D for rural areas and hence they will not employ students with that experience. I think one way out is to make students involved in R&D during their education. Whether they go for rural or urban problems is immaterial. Once the R&D bug gets into their head it will automatically manifest itself in innovative solutions.

This R&D bug should be put into these students even during their school days by following the US-based 'Maker Movement' (MM).[102] MM is a big rage in the U.S. now and is being fuelled by 3D printing technology. The U.S. had an old tradition of youngsters tinkering in their garages on amateur radios, making small household items, etc. With the computer revolution, youngsters stopped tinkering and moved into playing with their iPads, iPods, phones, etc. With 3D printing technologies U.S. schools are now making students interested in creating designs, toys and new inventions. Once bitten by this bug, it is assumed that the students will be more involved in engineering by innovating and creating hardware-oriented products during their college days.

This MM at school level is being followed by changes in the engineering curriculum in U.S. colleges where more emphasis is being put on students doing hardware-oriented projects rather than software and hence more courseware on workshop training has been introduced. This is what the engineering education was all about in 1940s and '50s!

We need to learn from MM and effect changes in our school and engineering college curriculum accordingly. Presently, most of the graduates of premier engineering

colleges like IITs and NITs, after finishing their engineering degree, opt for management programs (MBA) or go into the IT sector since it gives them excellent salary packages. The engineering education becomes a stepping stone for getting into these programs, and there is hardly any use of their engineering knowledge in their eventual jobs.

This trend hopefully can be reversed by modifying the engineering curriculum of these premier institutes so as to sensitize the students and make them aware of what R&D is and how it can be done. Later on, when they become corporate managers, they will have a healthy respect for R&D and may be able to initiate research programs in their own companies.

To do this it may be worthwhile to have the students in the last year of their engineering programs carry out a project which is almost like a thesis, in which they not only make a working model but also do experimentation on it. The curriculum could be modified so that the students are also taught courses which lay emphasis on how the technological developments work in producing better devices, or the history of modern technological developments. This will be more educational and enjoyable, rather than solving some archaic engineering problems which unfortunately has become the norm in most of the engineering courses. Naturally this will present a great challenge to the existing faculty members to motivate the students to do research, since a substantial number of these members even in premier institutions are not known for their research capabilities.

Together with emphasis on R&D there is also a need to have social entrepreneurship and technical management as course streams in engineering curriculum. Social entrepreneurship should not only teach the students about the problems of rural India but how to use solid engineering in solving them.

Similarly technical management course will help the students learn about technology and innovation management. This is very different from the present engineering-management route that most students take where they finally end up as financial managers in the industry.

Both the technology management and social entrepreneurship streams should be grounded in excellent engineering education. The rise of great entrepreneurship all over the world has been mostly guided by technology managers like Whitney of GE (with Irving Langmiur),[2] Steve Jobs of Apple, and Bill Gates of Microsoft, among others.

At the same time the students need to be encouraged to become rural-products entrepreneurs. There are quite a number of IITs and NITs who have entrepreneurship incubation cells which encourage students to become entrepreneurs but they are mostly in software-related areas for which venture funding is quite easily available.

Nevertheless it is heartening to see that a good number of young engineers from top engineering colleges have started becoming entrepreneurs in various fields. However these are mostly in urban areas, where they live and work. Thus they see opportunities in the urban markets only. Once they are sensitized to the rural markets we will see more of them in the field of precision farming, 3D manufacturing and other rural related areas.

It is necessary that venture funds should be available for developing rural products and markets. The GOI can help by creating a program of venture funds for rural innovations. Just like venture funds in the IT sector have helped spawn IT enterprises, so can the venture funds boost rural innovations.

In 2000 we almost set up the first rural venture fund for renewable energy[103] with United Western Bank (now IDBI). The U.S. partner, Winrock International, could not raise the necessary capital and there were also problems with UWB (it was merged into IDBI) so the fund was still-born. I feel now is the time to revive such ideas and funds.

The future of India belongs to the younger generation. All of us have to do our bit to get them involved in helping improve the lives of the rural poor. If we do not do so there will be serious social conflicts. The rise of the Maoist movement, which has engulfed one third of our country, is a pointer to the dangers of that. Unless we can

provide basic amenities so that the rural poor can live a meaningful life we will never become a great nation. This is a great challenge for all youngsters and it is my dream that they will take it up so as to make India a better place in which to live and work.

Link Notes

Chapter no.	Page no.	Ref. no.	URL	Description
I	4	1	www.nariphaltan.org/usexp.pdf	My book "1970s America –An Indian student's journey. Published in 2008 by NARI.
	7	2	www.nariphaltan.org/langmuirrural.pdf	Current Science article on use of high technology for rural areas. 2008
	7	3	www.nariphaltan.org/sorghum.pdf	Our work on sweet sorghum since early 1980s.
	7	4	www.nariphaltan.org/about-2/awards/	Awards list at NARI website.
	8	5	www.nariphaltan.org/bud.pdf	My syndicated article "Nipped in the bud"; on what ails our schooling system. 2013
	8	6	www.nariphaltan.org/iiteducation.pdf	My syndicated article on what ails IIT education. 2013.
	8	7	www.nariphaltan.org/iitb2013.pdf	2013 lecture to IIT Bombay students entitled "Have Junoon-Be Happy".
	9	8	www.nariphaltan.org/swachnari.pdf	Our small attempt in cleaning common toilets at NARI.
	9	9	www.nariphaltan.org/writings_files/sustainable.htm	All my articles on sustainable development.
	10	10	www.nariphaltan.org/writings.htm	All my articles on spirituality and other issues of rural development.
	10	11	www.nariphaltan.org/thoughtbook.htm	My book "Nature of Human Thought" which deals with issues of spirituality, technology and sustainability. Second edition 2010.
	10	12	www.nariphaltan.org/volunteers.pdf	Stories of interns who have come to our Institute from all over the world.
	10	13	www.nariphaltan.org/simplelife.htm	An essay on how I try to live simply in Phaltan.
	10	14	www.nariphaltan.org/spiritech.pdf	An op-ed article on how technology and spirituality are related. Times of India 2014.
	11	15	www.nariphaltan.org/givingback.pdf	An article published in Times of India on how giving back to society gives happiness.2013
	11	16	www.nariphaltan.org/writings_files/technical.htm	Our technical papers and writings on renewable energy.

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1	14	17	www.nariphaltan.org/dye.pdf	My paper in Journal of Solar Energy (1981) on effect of dyes on solar distillation.
	16	18	www.nariphaltan.org/solarstill.pdf	Our work on small solar powered alcohol distillation unit.1984
	28	29	www.nariphaltan.org/ethstove.pdf	Technical paper on low alcohol concentration stove. Published in Energy for Sustainable Development 2007.
	28	29	www.nariphaltan.org/ethstove.pdf	Technical paper on low alcohol concentration stove. Published in Energy for Sustainable Development 2007.
	16	3	www.nariphaltan.org/sorghum.pdf	Our work on sweet sorghum since early 1980s.
	17	18	www.nariphaltan.org/solarstill.pdf	Our work on small solar powered alcohol distillation unit.1984
	17	3	www.nariphaltan.org/sorghum.pdf	Our work on sweet sorghum since early 1980s.
	18	19	www.nariphaltan.org/ethanoldist.pdf	Technical paper on solar powered pilot plant for solar distillation of ethanol. 1991
	19	19	www.nariphaltan.org/ethanoldist.pdf	Technical paper on solar powered pilot plant for solar distillation of ethanol. 1991
	19	20	www.theguardian.com/news/1999/sep/03/guardianobituaries1	Details of David Hall.
	21	21	www.nariphaltan.org/pant.pdf	An obituary of my friend Shri. K.C.Pant. 2012
	22	22	www.nariphaltan.org/1986lanternreport.pdf	Complete data on various liquid fuel lanterns used in rural areas. Published in our first report on renewable energy. 1984.
	22	23	www.nariphaltan.org/lantern.htm	A report published by NARI on development of new lantern called Noorie.1989.
	22	23	www.nariphaltan.org/lantern.htm	A report published by NARI on development of new lantern called Noorie.1989.
	24	24	www.nariphaltan.org/Gasifier.pdf	Technical paper on sugarcane leaves gasification for industrial heat applications. 1997

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1	24	25	www.nariphaltan.org/detox.pdf	Report on NARI's work on solar detoxification of distillery waste. 2004
	24	26	www.nariphaltan.org/mobilityhistory.pdf	Our work on electric vehicles. NARI website.
	26	27	www.nariphaltan.org/lanstove.pdf	Report on ethanol lanstove developed at NARI.
	26	28	www.nariphaltan.org1986jantacooker.pdf	Report on work done on Janata cookers. From our first renewable energy booklet published in 1984.
	27	29	www.nariphaltan.org/ethstove.pdf	Technical paper on low alcohol concentration stove. Published in Energy for Sustainable Development 2007.
	27	30	www.nariphaltan.org/nari/pdf_files/housenergy.pdf	Current Science paper on Cooking and Lighting strategy for rural areas. Published in 2003.
	27	31	www.scidev.net/global/energy/feature/rediscovering-fire-in-the-21st -century.html	Response to my article in Sci. Dev. Net published in 2003.
	27	32	www.nariphaltan.org/pant.pdf	Eulogy of K.C.Pant.2012
	28	33	www.nariphaltan.org/pccaltem.pdf	Planning Commission document on cooking and lighting strategy for rural areas. 2004
	28	29	www.nariphaltan.org/ethstove.pdf	Technical paper on low alcohol concentration stove. Published in Energy for Sustainable Development 2007.
	28	29	www.nariphaltan.org/ethstove.pdf	Technical paper on low alcohol concentration stove. Published in Energy for Sustainable Development 2007.
	29	27	www.nariphaltan.org/lanstove.pdf	Report on ethanol lanstove developed at NARI.
	29	34	www.nariphaltan.org/globeforumaward.pdf	Details of Energy Globe Award given in Stockholm in 2009.

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1	29	34	www.nariphaltan.org/globeforumaward.pdf	Details of Energy Globe Award given in Stockholm in 2009.
	30	27	www.nariphaltan.org/lanstove.pdf	Report on ethanol lanstove developed at NARI.
	30	35	www.nariphaltan.org/kerolanstove.pdf	Technical paper giving details of kerosene lanstove. 2013.
	30	36	www.nariphaltan.org/sootpaper.pdf	A technical paper on measurement of soot in rural huts.
	30	35	www.nariphaltan.org/kerolanstove.pdf	Technical paper giving details of kerosene lanstove. 2013.
	30	36	www.nariphaltan.org/sootpaper.pdf	A technical paper on measurement of soot in rural huts.
	31	37	www.nariphaltan.org/statesmanstory.pdf	A lead story in Statesman newspaper about the lanstove testing in rural huts. 2013
	32	38	www.nariphaltan.org/kerosene.pdf	2013 Current Science article on the issue of kerosene.
	32	39	www.nariphaltan.org/watersterlization.pdf	A Current Science article on water sterilization at sub - boiling temperatures. 2013
	32	40	www.firstpost.com/fwife/sari-sun-combo-can-sterilise-dirty-water-619304.html	A news story on our Current Science paper on water sterilization. 2013
	33	41	www.nariphaltan.org/ruralrestaurants.pdf	A syndicated article on our work on rural restaurants was published all over the world. 2011
	33	41	www.nariphaltan.org/ruralrestaurants.pdf	A syndicated article on our work on rural restaurants was published all over the world. 2011
	33	42	www.nariphaltan.org/dreamvillage.pdf	An editorial article in Times of India. 2005
	34	12	www.nariphaltan.org/volunteers.pdf	Stories of interns who have come to our Institute from all over the world.
2	36	43	www.nariphaltan.org/EI.pdf	A technical note published in our renewable energy repot of 1984 describing the concept of Energy Index.

Chapter no.	Page no.	Ref. no.	URL	Description
2	36	44	www.nariphaltan.org/gasbook.pdf	A very popular CRC book chapter on Biomass gasifiers written by NARI. Published in 1986.
	36	44	www.nariphaltan.org/gasbook.pdf	A very popular CRC book chapter on Biomass gasifiers written by NARI. Published in 1986.
	38	45	www.nariphaltan.org/woodgasifier.pdf	A technical paper on our work on small scale wood gasifier. Published in Intl Journal of Biomass. 1989.
	38	46	www.nariphaltan.org/gasifierelec.pdf	A technical paper on our small scale sugarcane leaves gasifier published in Biomass and Bioenergy. 1995.
	39	47	www.nariphaltan.org/gasificationresearch.pdf	Keynote paper on gasification presented at Vadodra conference in 1990.
	40	46	www.nariphaltan.org/gasifierelec.pdf	A technical paper on our small scale sugarcane leaves gasifier published in Biomass and Bioenergy. 1995.
	42	24	www.nariphaltan.org/Gasifier.pdf	Technical paper on sugarcane leaves gasification for industrial heat applications. 1997
	43	24	www.nariphaltan.org/Gasifier.pdf	Technical paper on sugarcane leaves gasification for industrial heat applications. 1997
	43	48	www.nariphaltan.org/syrup.pdf	Technical paper on syrup from sweet sorghum.
	44	49	http://en.wikipedia.org/wiki/Stirling_engine	A general article from Wikipedia about Stirling Engines.
	45	50	www.nariphaltan.org/gasificationresearch.pdf	Keynote paper on gasification presented at Vadodra conference in 1990.
3	47	51	www.nariphaltan.org/energy1986.pdf	My paper presented in the Maharashtra Conference held in Mumbai in 1986.
	47	51	www.nariphaltan.org/energy1986.pdf	----------------------------do---------------------------
	50	52	www.nariphaltan.org/pacer.pdf	NARI's PACER study on Taluka energy self-sufficiency. 1990.

Chapter no.	Page no.	Ref. no.	URL	Description
3	50	52	www.nariphaltan.org/pacer.pdf	----------------------------do------- ----------------
	51	53	www.nariphaltan.org/mnes.pdf	MNES documents announcing the policy on Taluka energy plan.
	51	54	http://en.wikipedia.org/wiki/Providing_Urban_Amenities_to_Rural_Areas	Wikipedia article on PURA.
	52	52	www.nariphaltan.org/pacer.pdf	NARI's PACER study on Taluka energy self-sufficiency. 1990.
	52	55	http://timesoffindia.indiatimes.com/home/opinion/edit-page/LEADER-ARTICLE-Farming-For-Energy/articleshow/2101442.cms	Lead editorial article in Times of India "Farming for Energy". 2007
	53	56	http://nariphaltan.org/ruralelec.pdf	NARI's technical study on power requirements for a village and how it can be met. 2005
	53	57	http://nariphaltan.org/EW.pdf	NARI's study on how energy and water requirements of a village could be met by creative solutions. 2005
	53	58	http://en.wikipedia.org/wiki/Organic_Rankine_cycle	Wikipedia article on organic Rankine cycle.
	53	59	www.nariphaltan.org/solar.htm	NARI study on how solar energy can be used through organic Rankine cycle for rural applications. 2009
	53	60	www.nariphaltan.org/epw.pdf	
	53	61	www.iisc.ernet.in/~currsci/mar252002/632.pdf	
4	55	62	www.nariphaltan.org/rickshawnote.pdf	A note prepared by NARI in 1983 on cycle and rickshaw improvement and sent to Shri H.N.Bahuguna
	55	19	www.nariphaltan.org/ethanoldist.pdf	Technical paper on solar powered pilot plant for solar distillation of ethanol. 1991
	55	63	www.nariphaltan.org/gasifierhistory.pdf	A short history of our work on gasification. 2014

Chapter no.	Page no.	Ref. no.	URL	Description
4	55	64	www.ieeeghn.org/wiki/index.php/Oral-History:Henry_Oman	An oral history of Henry Oman
	55	65	http://engineering.oregonstate.edu/henry-oman-2005-engineering-hall-fame	A short biographical sketch of Henry Oman
	57	66	http://nariphaltan.org/ecoreport.pdf	NARI report on cycle improvement submitted to E&Co, NY in 1997.
	57	67	www.nariphaltan.org/etarticle.pdf	Editorial article in Economic Times 1996.
	57	68	http://nariphaltan.org/research/renewable-energy/mobility/	NARI's work on mobility issues.
	59	69	www.nariphaltan.org/MAPRA.pdf	Current Science article on rickshaw improvement published in 2002
	60	70	www.nariphaltan.org/IEricksstory.pdf	Indian Express news story on our work on rickshaws. 2002
	60	71	http://nariphaltan.org/html/wonder.html	Major story in HINDU on our rickshaw development work. 2003
	63	68	http://nariphaltan.org/research/renewable-energy/mobility/	NARI's work on mobility issues.
	64	72	www.decanherald.com/content/100289/csirs-solar-rickshaw-finds-no.html	Syndicated article published in all major newspapers on the issue of CSIR Soleckshaw. 2010
	64	73	www.nariphaltan.org/petal.pdf	A technical paper on our work of solar-powered safflower petal collector. 2005
	65	74	www.zeromotorcycles.com/zero-s/specs.php	Electric motorbikes description. This is being given as an indication of the type of the technologies available. The author is not endorsing this company.
	65	75	www.asphaltandrubber.com/popular/02-pursuit--air-powered-dirt-bike/	Type of air powered motor bikes available. The author is not endorsing this company.
5	68	76	www.uman.ece.ufl.edu/resumes/Uman_Short_Bio_October_2010.pdf	A short biographical sketch of Dr. Uman.
	68	77	www.nariphaltan.org/langmuir.pdf	An article on Irving Langmuir published in Resonance Journal. 2008
	68	17	www.nariphaltan.org/dye.pdf	My paper in Journal of Solar Energy (1981) on effect of dyes on solar distillation.

Chapter no.	Page no.	Ref. no.	URL	Description
5	69	78	www.nariphaltan.org/desalination.pdf	A technical paper published in International Solar Energy Journal in 1980
	70	79	www.nariphaltan.org/householdhistory.pdf	The history of rural household energy work at NARI. 2014
	70	63	www.nariphaltan.org/gasifierhistory.pdf	History of gasification R&D at NARI. 2014
	71	80	www.nariphaltan.org/dew.pdf	A technical paper on dew condensation published in International Journal of Desalination. 1981.
	71	80	www.nariphaltan.org/dew.pdf	A technical paper on dew condensation published in International Journal of Desalination. 1981.
	72	81	http://en.wikipedia.org/wiki/Phaltan	A Wikipedia article on Phaltan
	72	82	http://nariphaltan.org/weather.pdf	A technical paper on the analysis of 30 years weather data from our weather station at NARI. 2006
	73	83	www.nariphaltan.org/watersterilization.pdf	A technical paper published in Current Science in 2013.
	74	84	www.nariphaltan.org/SWEE.pdf	A technical paper published in Proceedings of International Solar Energy conference. 1991.
	75	25	www.nariphaltan.org/detox.pdf	Our dew paper published in Desalination Journal. 1981.
	76	80	www.nariphaltan.org/dew.pdf	A technical paper on dew condensation published in International Journal of Desalination. 1981.
6	78	85	http://time.com/2999550/india-home-to-most-poor-people/	Time magazine story about the World Bank Report. 2013.
	79	74	www.zeromotorcycles.com/zero-s/specs.php	Electric motorbikes description. This is being given as an indication of the type of the technologies available. The author is not endorsing this company.
	79	75	www.asphaltandrubber.com/popular/02-pursuit--air-powered-dirt-bike/	Type of air powered motor bikes available. The author is not endorsing this company.
	79	35	www.nariphaltan.org/kerolanstove.pdf	Technical paper giving details of kerosene lanstove,2013.

Chapter no.	Page no.	Ref. no.	URL	Description
6	79	86	http://planningcommission.gov.in/reports/genrep/rep_intengy.pdf	Planning Commission policy document on energy released in 2006.
	80	87	http://en.wikipedia.org/wiki/3D_printing	Wikipedia article on 3-D printing.
	81	88	www.nariphaltan.org/ncsd	Bajaj Center of Sustainable development at NARI.
	82	89	http://outlookindia.com/article/How-Much-Can-We-Forgo-To-India-Inc/291424	An Outlook magazine article by P.Sainath on the issue of subsidy for corporates! 2014
	82	90	www.nstmis-dst.org/SnT-Indicators2011-12.aspx	DST data on expenditure on R&D in all GOI establishments in India. 2011
	82	91	http://en.wikipedia.org/wiki/Corporate_social_responsibility	A Wikipedia article on CSR.
	83	92	www.nariphaltan.org/farmenergy.pdf	An editorial article in Times of India. 2007
	84	24	www.nariphaltan.org/Gasifier.pdf	Technical paper on sugarcane leaves gasification for industrial heat applications. 1997
	84	93	http://opensourceecology.org/wiki/Pyrolysis_Oil	Encyclopedia article on pyrolysis oil.
	84	94	www.nariphaltan.org/economy.htm	My article in Sci. Dev. Net on the renewable energy economy and job creation. 2009
	86	95	www.nariphaltan.org/capart.htm	An article in CAPART Journal published in 1992.
	86	96	http://en.wikipedia.org/wiki/Jugaad	A Wikipedia article on Jugaad.
	86	97	http://nariphaltan.org/precisionagriculture.pdf	My syndicated article on precision agriculture published all over the world. 2013.
	87	97	http://nariphaltan.org/precisionagriculture.pdf	My syndicated article on precision agriculture published all over the world. 2013.
	87	97	http://nariphaltan.org/precisionagriculture.pdf	My syndicated article on precision agriculture published all over the world. 2013.
	88	98	www.nariphaltan.org/humanthought.pdf	From the book “Nature of Human Thought”. 2010.
	88	99	www.nariphaltan.org/gandhiessay.pdf	My essay in the book “Timeless Inspirator-Reliving Gandhi” (Ed. R.A.Mashelkar). 2010

Chapter no.	Page no.	Ref. no.	URL	Description
6	88	41	www.nariphaltan.org/ruralrestaurants.pdf	A syndicated article on our work on rural restaurants was published all over the world. 2011
	89	100	http://en.wikipedia.org/wiki/The_Electricity_Act_2003	Wikipedia article on India's Electricity Act 2003.
	90	5	www.nariphaltan.org/bud.pdf	My syndicated article "Nipped in the bud"; on what ails our schooling system. 2013
	90	6	www.nariphaltan.org/iiteducation.pdf	My syndicated article on what ails IIT education. 2013.
	91	101	www.nariphaltan.org/	NARI website link
	91	7	www.nariphaltan.org/iitb2013.pdf	2013 lecture to IIT Bombay students entitled "Have Junoon-Be Happy".
	91	1	www.nariphaltan.org/usexp.pdf	My book "1970s America –An Indian student's journey. Published in 2008 by NARI.
	91	15	www.nariphaltan.org/givingback.pdf	An article published in Times of India on how giving back to society gives happiness.2013
	92	102	http://www.csmonitor.com/innovation/2014/0706/The_maker_movement-creates-D.I.Y.-revolution	An article in Christian Science Monitor on Maker Movement. 2014
	93	2	www.nariphaltan.org/langmuir.pdf	Current Science article on use of high technology for rural areas. 2008
	94	103	http://www.financialexpress.com/old/fe/daily/20001028/fco28051.html	Financial Express news item on NARI-UWB collaboration on setting up a fund for renewable energy for rural areas.

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